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SIMULATED OCCUPANCY TESTS AND AIR DISTRIBUTION IN A 480-PERSON COMMUNITY FALLOUT SHELTER

Oddvar W. Svaeri, and Michael M. Dembo

Protective Structures Development Center,
Fort Belvoir, Virginia

1965

AD

PSDC - TR - 23

FINAL REPORT

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For

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PROTECTIVE STRUCTURES DEVELOPMENT CENTER

Joint Civil Defense Support Group
Office of Chief of Engineers
Department of the Army
Washington, D. C. 20315

Office of Civil Defense Work Order No. OCD - PS - 65 - 17
Subtask No. 1217A

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DETACHABLE SUMMARY

PSDC-TR-23

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Technical Report Prepared by
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Washington, D. C. 20315

For

Office of Civil Defense
Office of the Secretary of the Army
Washington, D. C. 20310
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These tests, using simulated occupancy, were conducted to determine the ventilation rate required to maintain a habitable thermal environment in a 480-person community fallout shelter. Of particular note are the effects of auxiliary air moving devices, such as punkahs, on the air distribution patterns created by the building ventilation system.

The shelter was an above ground, one story structure with inside plan dimensions of 60 by 80 feet. The cores and hollow cavity of the concrete masonry units exterior bearing walls were sandfilled for radiation shielding. Sandfilling was also used to form the radiation shielding barrier for the roof. The punkahs used were an adaptation of the oriental cloth covered frame which is suspended from the ceiling and used for fanning a room.

The ventilation air was conditioned in accordance with the diurnal temperature and humidity conditions for the Davison Field, Ft. Belvoir Area, based on a 10% design day. The ventilation rate required to maintain a tolerable thermal environment was determined to be 15 cfm per person. This was based on an occupant loading rate of 10 square feet per person and an average effective temperature of 82 over a 24-hour period. This experimentally determined ventilation rate is in agreement with the rate established by the Office of Civil Defense for analysis of the thermal environment in shelters.

To observe the effects of overcrowding, the latent and sensible heat outputs of the simulated occupants were increased to that of 680 persons, which is equivalent to a loading rate of 7.5 square feet per person. The 82 average effective temperature was exceeded when the test was prolonged for a 48-hour period following thermal stabilization of the shelter with a ventilation rate of 15 cfm. The average effective temperatures of 83.1 and 83.3 were observed.

The air distribution patterns were observed and air velocity vectors were plotted for various combinations of punkahs and the two dual unit exhaust fans (total capacity 7200 cfm or 15 cfm per occupant) which were the installed ventilation system. It was found that punkahs provided a more equitable distribution of the ventilation air by preventing stratification and disrupting the channelizing effects of the building exhaust ventilation system.

SUMMARY

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FOREWORD

This report presents results of simulated occupancy tests evaluating the thermal response and distribution of ventilation air in a prototype 480-person dual-purpose community fallout shelter.

These tests were authorized and funded by the Office of Civil Defense and performed under Work Orders OCD-PS-65-17 (8 October 1964) and DAHC20-67-W-0111 (15 July 1966), subtask 1217A. The work was conducted during August and September 1966.

The authors wish to express their appreciation to all who participated in the tests. In particular, we wish to acknowledge the contributions of:

Mr. Cresson H. Kearny of the Oak Ridge National Laboratory for his contribution in formulating the basic concept of the directional punkah.

Mr. E. DeLauder of the Protective Structures Development Center for his resourcefulness in development, installation and maintenance of special instrumentation.

Mr. R. F. Stellar is Chief of the Joint Civil Defense Support Group and Mr. M. M. Dembo is the Chief of the Protective Structures Development Center; the tests covered in this report were made under their supervision.

CONTENTS

CHAPTER 1

INTRODUCTION

1.1 OBJECTIVES

a. To determine the optimum ventilation rate for the shelter structure at an occupant loading rate of 10 square feet per person (480 occupants) when supplied with ventilation air conditioned to simulate a 10% design day in the Washington, D. C. area. Thermal reaction of the structure due to the occupant loading and the solar loading will be observed, as well as effective temperature within the shelter.

b. Determine the thermal conditions within the shelter at a loading rate of 7.5 square feet per person using the ventilation rate determined in the first phase described above.

c. Observe the air distribution patterns of the ventilation system designed for the shelter and changes in these patterns created by use of auxiliary air moving devices.

1.2 BACKGROUND

<u>1.2.1 Simulated Occupancy Tests</u>. The Office of Civil Defense (OCD), beginning in 1962, sponsored a series of simulated occupancy tests of selected fallout shelters to obtain a soultion to the problem of providing a habitable environment in shelters with minimal ventilation equipment. These tests were designed to: (a) Provide empirical data on optimum (minimal) ventilation rates needed to maintain a tolerable environment within the shelter, and (b) furnish experimentally determined parameters for concurrent analytic studies of the thermal response of shelters to varying internal loading and ambient conditions. Results of these tests are available in the literature.[1,2,3*]

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*Superscript numerals refer to material in References.

The particular shelter evaluated in this report was an aboveground, one-story 480-person dual-purpose community shelter. The shelter is described in Chapter 2.

1.2.2 Evaluation of Shelter Environment. The criterion used for judging the habitability of a particular shelter, with respect to its thermal environment, is the effective temperature index developed by the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE).[4] This effective temperature index is an empirically determined index of the degree of warmth perceived on exposure to different combinations of temperature, humidity and air movement. The actual effective temperature to be used in fixing the habitability of a particular shelter has not yet been firmly established; however, it is generally agreed that for humans, effective temperatures over 82 are excessive for protracted periods. For the purposes of this report, the shelter is considered habitable if the average effective temperature over a 24-hour period does not exceed 82.

CHAPTER 2

INVESTIGATION

2.1 480-PERSON DUAL PURPOSE COMMUNITY FALLOUT SHELTER

The basic shelter design was a rectangular aboveground one-story structure, 60 by 60 feet inside dimensions. The unique feature of the design was the sandfilled wall and roof construction. Exterior and shielding baffle walls were made of two 8-inch hollow concrete masonry units separated by a 1-foot wide cavity. The hollow masonry units and the cavity were filled with sand. Roof construction consisted of steel bar joists and metal covering which together supported an average 14-1/2 inches of sandfill plus a 2-1/2 inch thick concrete cover slab. (See Figures 2.1 and 2.2) This type of austere construction was used to obtain radiation shielding of PF 100.

Based on an OCD concept, the prototype dual purpose structure was designed to facilitate ease and economy of initial construction with subsequent improvements (plumbing, heating, etc.) over a period of time to provide additional conventional uses. While designed primarily as a community fallout shelter (capacity 480 persons), it can be modified and expanded into a building capable of serving other purposes, such as a community center, municipal building, or recreational facility.

The prototype shelter at PSDC has been utilized for display purposes as well as for housing the Center's machine shop and part of the test facilities. Elevations of the building are shown in Figures 2.3 and 2.4.

2.2 EQUIPMENT AND TEST PROCEDURES

2.2.1 Ventilation Rates. Ventilation air was supplied to the shelter in accordance with the diurnal temperature and humidity variations shown in Appendix A, which represent a 10% design day in the Washington, D. C., area. This chart was developed from five-year averages of weather data obtained from the weather station at the U. S. Army Davison Air Field, Fort Belvoir, Virginia. The detailed procedure used for determining the diurnal day is furnished in Appendix A.

Starting ventilation rates for the tests were obtained from Drucker[5] and U. S. Army Corps of Engineers sources.[6] These references indicate, based on the 10% design day in the Washington, D. C. area, that a ventilation rate of 15 cfm per occupant will maintain an 82 or lower average shelter effective temperature over a 24-hour period. The tests were started with this rate and varied to reach an optimum internal temperature condition in relation to an 82 average effective temperature. The OCD Environmental Control and Instrumentation Trailer was used to supply the conditioned air (Figure 2.1). The output of the computer program, developed by Drucker for determining ventilation rates, required to attain a given effective temperature in a shelter, is furnished in Appendix B.

2.2.2 Simulated Occupants. Individual and multiple simulated occupants (Simoc) were used to generate the internal heat load to measure the shelter response, i.e., effective temperatures prevailing within the shelter. However, when air distribution patterns were

measured, the multiple Simocs could not be used because of the disturbing effect the fans had on the true shelter air flow patterns. During these tests electric heaters and a steam boiler were used in place of the multiple Simocs. Figures 2.5 and 2.6 show the interior of the test shelter with both types of Simocs in place. A detailed description of the individual Simoc is furnished in technical report PSDC-TR-17.[7] The multiple or mass Simoc shown in Figure 2.5 consists of a fan, a variable electric heater, a sensitive metering pump and a whirling disc type atomizing humidifier. Heated air is supplied by the fan to the atomized water droplets resulting in a predetermined quantity of air being supplied to the shelter in prescribed portions of latent and sensible heat. By varying the output of the electric heaters and the amount of water delivered to the atomizer, the Simoc can be made to simulate the heat load given off by from 5 to 60 persons.

Figure 2.7 shows a floor plan of the shelter, including the steam distribution loop used during the air distribution phase of the test program. Note that the fan discharge, of the multiple Simoc, was directional and disturbing to the air flow patterns to be measured; hence steam lines were used to supply the latent heat load during this phase of the tests. The steam boiler installation and gravity water supply tanks used to supply the Simocs are shown in Figure 2.8.

2.2.3 Environmental Control and Instrumentation Trailer. Conditioned air to ventilate the test shelter was supplied from the Environmental

Control and Instrumentation Trailer, see Figures 2.3 and 2.7. The trailer is a mobile air conditioning plant capable of delivering air simulating the diurnal and seasonal variations of temperatures and humidity conditions prevailing in many parts of the United States. The miscellaneous instrumentation and controls used in the operation of the trailer and for monitoring and recording test data are in the trailer cab, see Figure 2.7.

2.2.4 Shelter Ventilation Fans. The shelter ventilation system consisted of two dual fan, air handling units installed in the South wall of the building, see Figure 2.10. Air is drawn in through two louvered openings in the northeast and northwest corners of the building, travels through the shelter and is exhausted by the dual air handlers. The total capacity of these two units is 7200 cfm or 15 cfm per occupant (480 persons, allowing 10 square feet per person). The fans were not used when air was supplied from the trailer. The locations of the exhaust fans and air inlets are shown in Figure 2.7. The louvered inlet, in the northeast corner of the shelter, and a hygrosensor head, used to record inlet air conditions, are depicted in Figure 2.11.

2.2.5 Air Moving Devices. The effects of auxiliary air moving devices were evaluated during the air distribution pattern tests. Ambient air was supplied to the shelter at a constant rate during this phase and the air moving device tested was the "punkah." This punkah, a modification of the original oriental cloth covered frame, was a manually operated pendulum-like fan which moves air in a single direction.

It consisted of a rectangular wood (or metal) frame with outside dimensions 36 inches high by 28 inches wide covered with chicken wire (or nylon netting) serving as backstop for a series of 4 inch wide polyethylene flaps. The flaps were double hemmed on one edge to receive a wire hinge on which they could swing freely. The top end of the punkah frame was hinged enabling it to swing with a pendulum-like motion when pulled, during the power stroke, by a cord attached to the closed flap-valve side. The swinging punkah caused air to move in the direction of the pull. At the beginning of the power stroke the polyethylene flaps close and at the end of the power stroke, the punkah is released and swings back as a pendulum. As the back stroke starts, the flap-valves open and the air stream, set in motion during the power stroke, continues to flow through the now open flap-valves. As the punkah reached its maximum back stroke, a pull on the cord repeats the cycle, see Figure 2.12. During these tests, the punkahs were all operated by electrically driven variable speed drives, geared to speeds simulating manual operation.

A complete description of these devices, including operating characteristics and fabrication details, is furnished in technical report PSDC-TR-21/22.[8]

2.2.6 Instrumentation and Data Recording.

2.2.6.1 Temperature Measurements. The temperatures within the test shelter were generally measured by copper-constantan thermocouples

and were recorded once each hour on multi-point recording potentiometers located in the operator's cab of the trailer. A total of 133 thermocouples and 11 temperature and wide range humidity sensing elements (hygrosensors) were used. Their locations are shown in Appendix C. The effective temperatures within the shelter were determined, using the data obtained by the hygrosensors, from the ASHRAE effective temperature chart. The air flow from the trailer was measured by making a 16-point velocity traverse of the discharge opening of the trailer supply duct in the plenum, using an Alnor (direct displacement vane-type anemometer) velometer. The dry and wet bulb temperatures of the supply and exhaust air, as well as the shelter internal temperature and humidity and several wall, ceiling, and floor thermocouple probes were continuously observed and plotted during the tests. These continuous plots served as a monitor for the various test operations and were valuable for detecting malfunctioning of equipment or errors in procedure. The curves of these plots are shown in Figures 3.1 through 3.8. They provided a direct means of ascertaining when steady state conditions were reached in the structure and at which condition the temperature curves became nearly level or uniformly cyclic.

2.2.6.2 Air Velocity Patterns. The effects of punkahs on the air distribution and velocity patterns, within the shelter rooms, were determined by injecting titanium tetra-chloride (white smoke) into the air stream from a smoke gun. The air velocity vectors were determined by injecting smoke into the air to ascertain the direction

of the vector and then measuring its magnitude with a hot wire anemometer, (Flowtronic (Flow Corporation, Cambridge, Mass.) Model 55B1 anemometer, having (0-10, 10-200, 25-4000) scales in fpm). Instrument accuracy was 5% of the reading, plus or minus 2 fpm, to 1,000 fpm and 5% of the reading over 1,000 fpm. Care was taken to hold the sensing wire of the anemometer perpendicular to the direction of the velocity vector maximizing the meter's accuracy and sensitivity. Typical shelter air distribution patterns and velocity magnitudes observed during the tests are presented in Appendix D. Note that measurements were taken at two levels in the shelter, 1 foot and 5 feet above the floor.

2.2.7 Test Procedures.

2.2.7.1 Phase I. In determining the optimum shelter ventilation rate, air conditioned to simulate the 10% summer design day, was supplied to the shelter at 15 cfm per occupant. This flow rate was then varied to give our criterion of 82 ET. Successive trials at varying flow rates were then made until the average effective temperature approached 82 and variations over a 24-hour period became substantially repetitive indicating steady state conditions had been obtained. At this stage, the temperatures within the structure walls, floor, and ceiling were also observed to be steady or uniformly cyclic. The ventilation rate at this point was considered as the optimum ventilation rate, i.e., the minimum air flow required to maintain an average 82 effective temperature over a 24-hour period for the given simulated ambient conditions.

2.2.7.2 Phase II. The effective temperature conditions within an overcrowded shelter were determined by increasing the heat

load, generated by the occupants, to that of 640 occupants with a loading rate of 7-1/2 sq ft per person. The steam boiler was used to generate the latent heat load corresponding to 160 additional occupants while the heat output from the 10 mass Simocs was increased. Ventilation air, conditioned to simulate the 10% design day, was supplied at the optimum rate established in Phase I.

2.2.7.3 Phase III. Air distribution patterns in the shelter were observed to determine the effectiveness of the installed ventilation system independently and in combination with auxiliary air moving devices (punkahs). The two exhaust fans in the south wall, capable of exhausting 15 cfm per occupant (480 occupants), were used to provide ambient air drawn in through the louvered openings in the northeast and northwest corners of the building. This created ventilation air flow through the shelter area with exhaust at the fan locations. The steam boiler was used to supply the latent heat load of 380 occupants, while the sensible load was furnished by six electric space heaters. The 100 individual Simocs provided the heat load for the balance of 480 occupants.

The distribution of air in the shelter was observed for the following configurations (arranged by date of test):

6 September

a. A velocity traverse was made at the 1 foot and 5 foot levels with ventilation drawn in by the exhaust fans in the south wall.

This traverse was made to measure the basic north-south air flow pattern within the shelter without auxiliary air moving devices.

b. Four punkahs were installed in pairs at about the third points of the building, measured parallel to the long building dimension, pumping air transverse to the basic air flow pattern. The two northerly punkahs imparted an easterly flow to the ventilation air while the pair at the south end forced the air towards the west. Only the directions of the velocity traverses were plotted for the one and five foot levels.

7 September. The four punkahs were arranged in pairs in two rows in the mid-portion of the shelter pumping air towards the north wall, i.e., opposite to the direction of the basic air flow caused by the building exhaust fans.

8 September. The punkahs were placed to move the air parallel to the long sides of the building, one pair forcing air in the same direction as the normal air flow and the other pair forcing air opposite to the basic flow pattern. All punkahs were then rearranged, in their same locations, to move the air in the same direction as the basic flow pattern.

9 September. The punkahs were placed in line, in the middle portion of the building, moving air towards the south wall, i.e., in the same direction as the air flow. Later the punkahs were reversed to divert the air towards the north wall opposite to the basic flow pattern. The objective, in opposing the basic flow pattern, was to disrupt the flow in the center of the building and force the air to move along the east and west walls making for a more uniform distribution of temperature in the shelter.

The location of the punkahs and the resultant velocity patterns are shown in Appendix D.

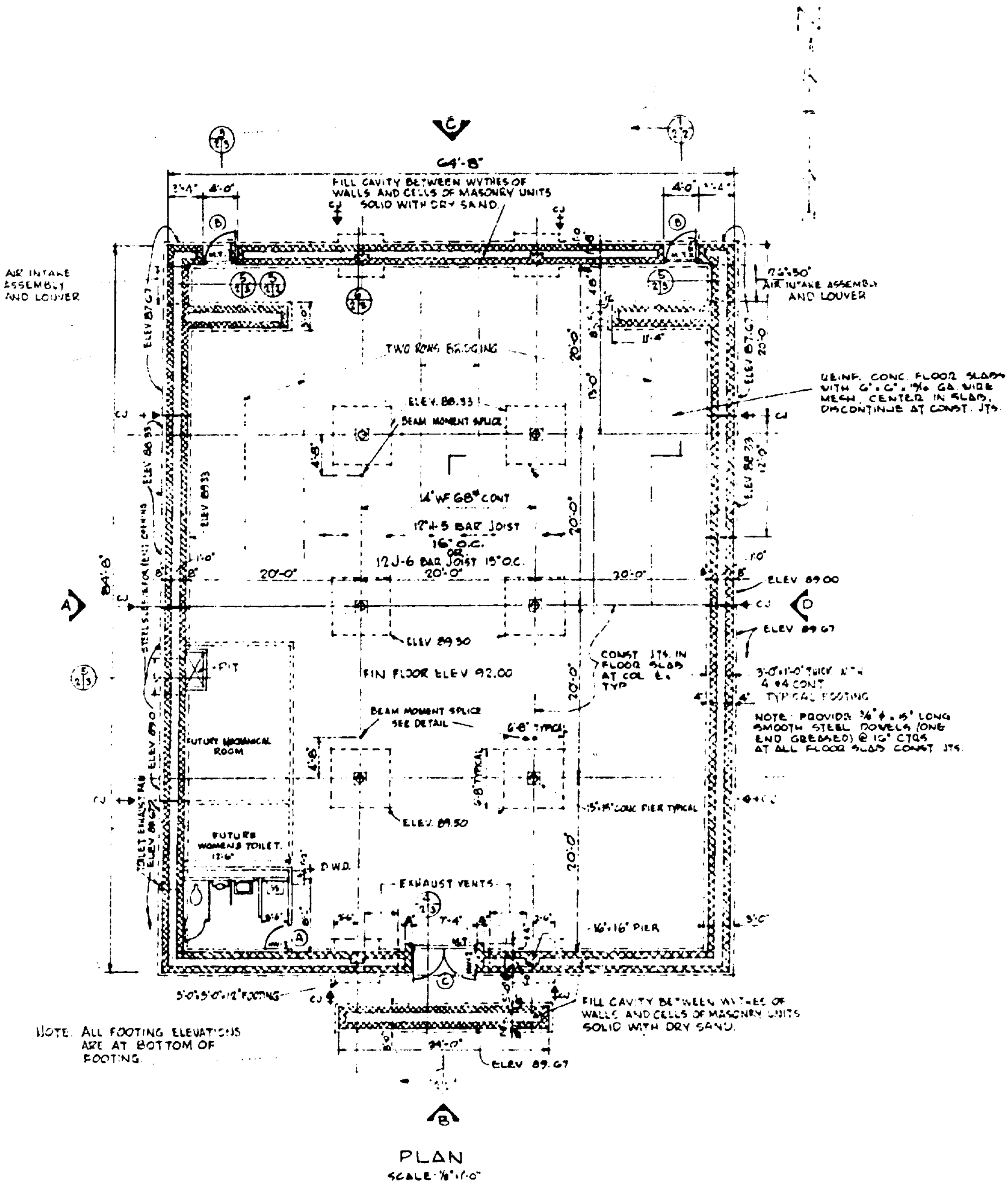


Figure 2.1 Floor Plan, 480-Person Community Fallout Shelter.

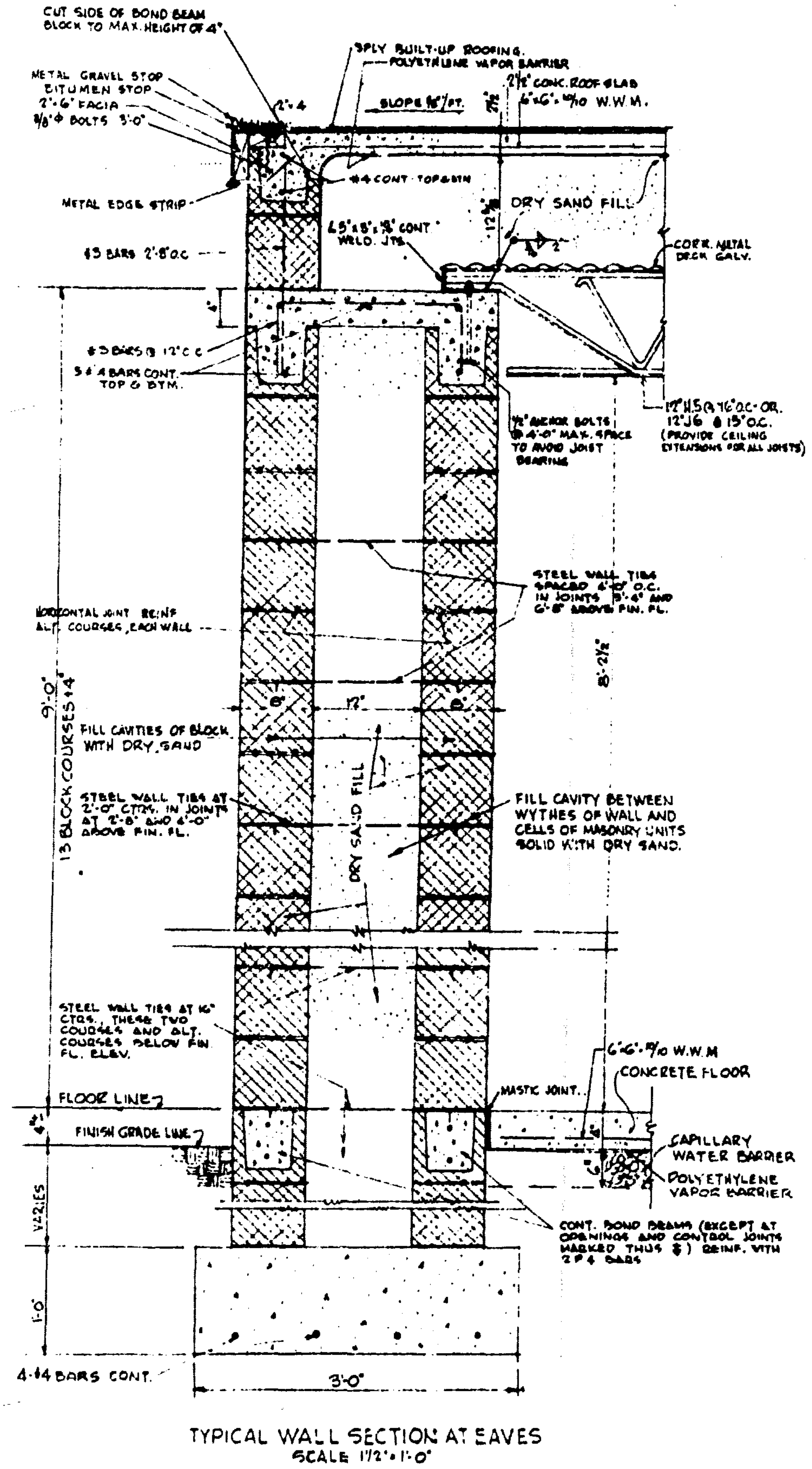


Figure 2.2 Wall Section, 480-Person Community Fallout Shelter.

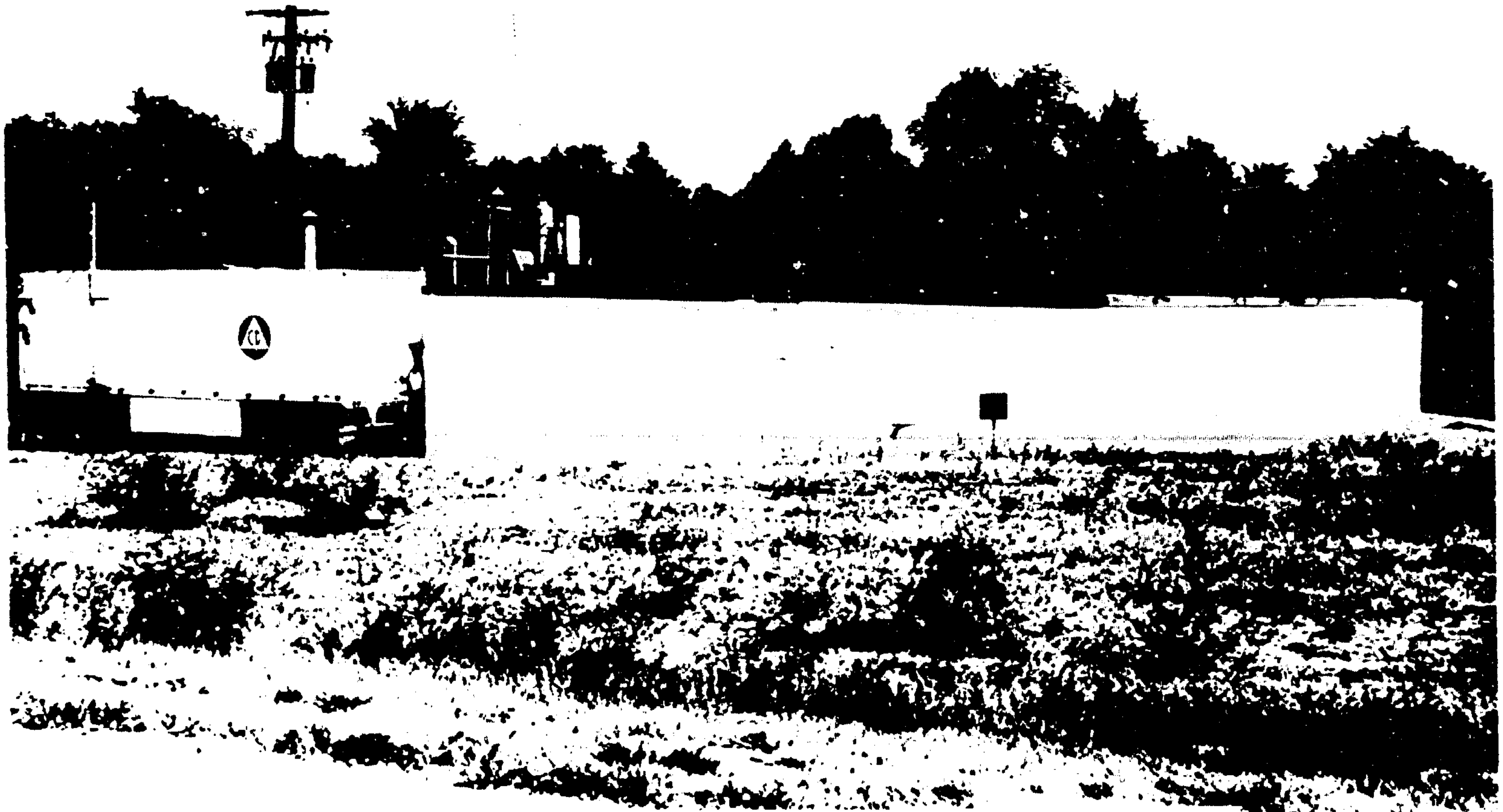


Figure 2.3 480-Person Community Fallout Shelter, south elevation with Environmental Control and Instrumentation Trailer.

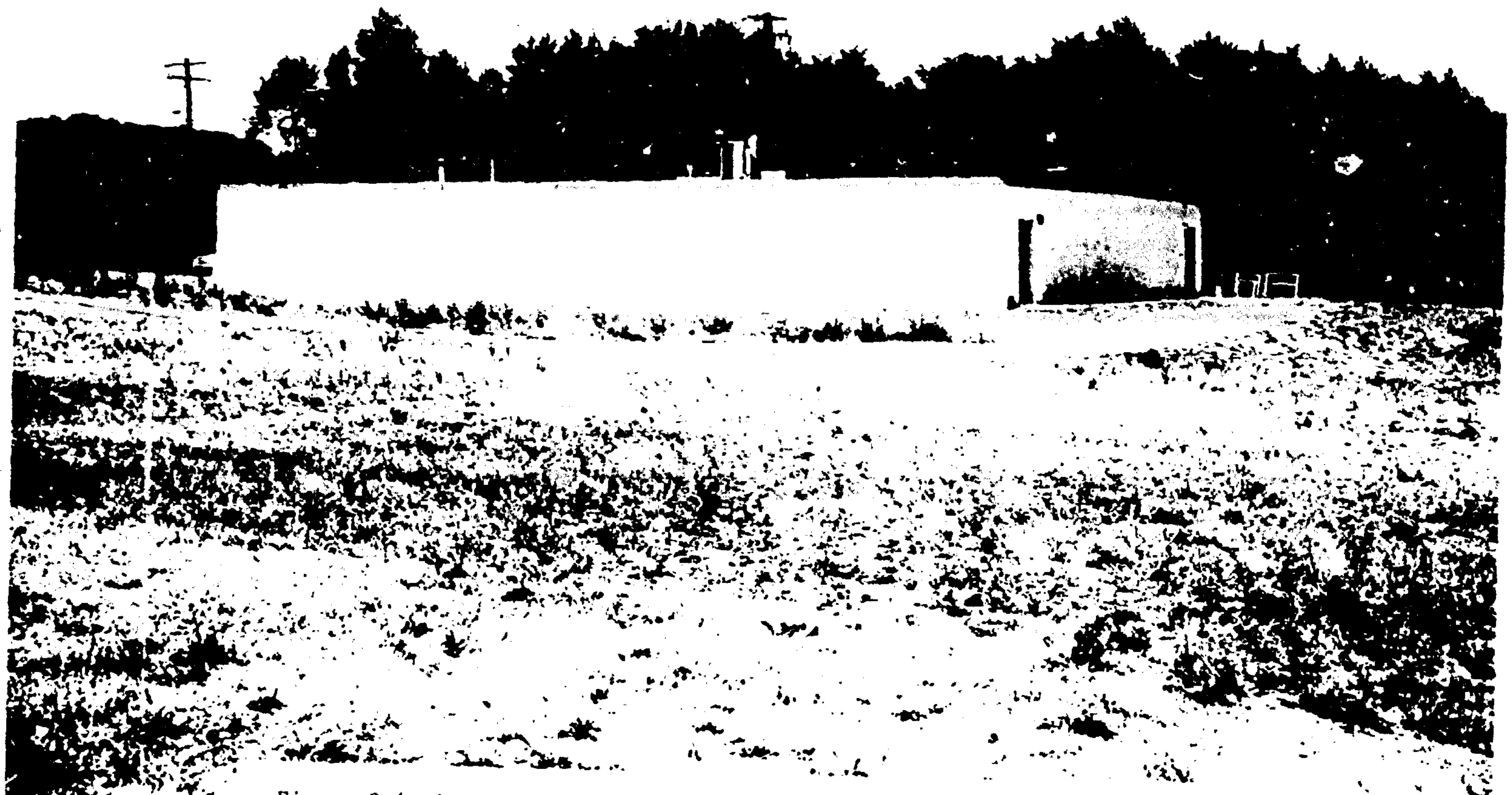


Figure 2.4 480-Person Community Fallout Shelter, northeasterly elevation.

Figure 2.5 Interior view of the test shelter (north) with individual and multiple simocs.

Figure 2.6 Interior view of the test shelter (south) with instrumentation; thermocouples, RH recorder and hygrosensor head.

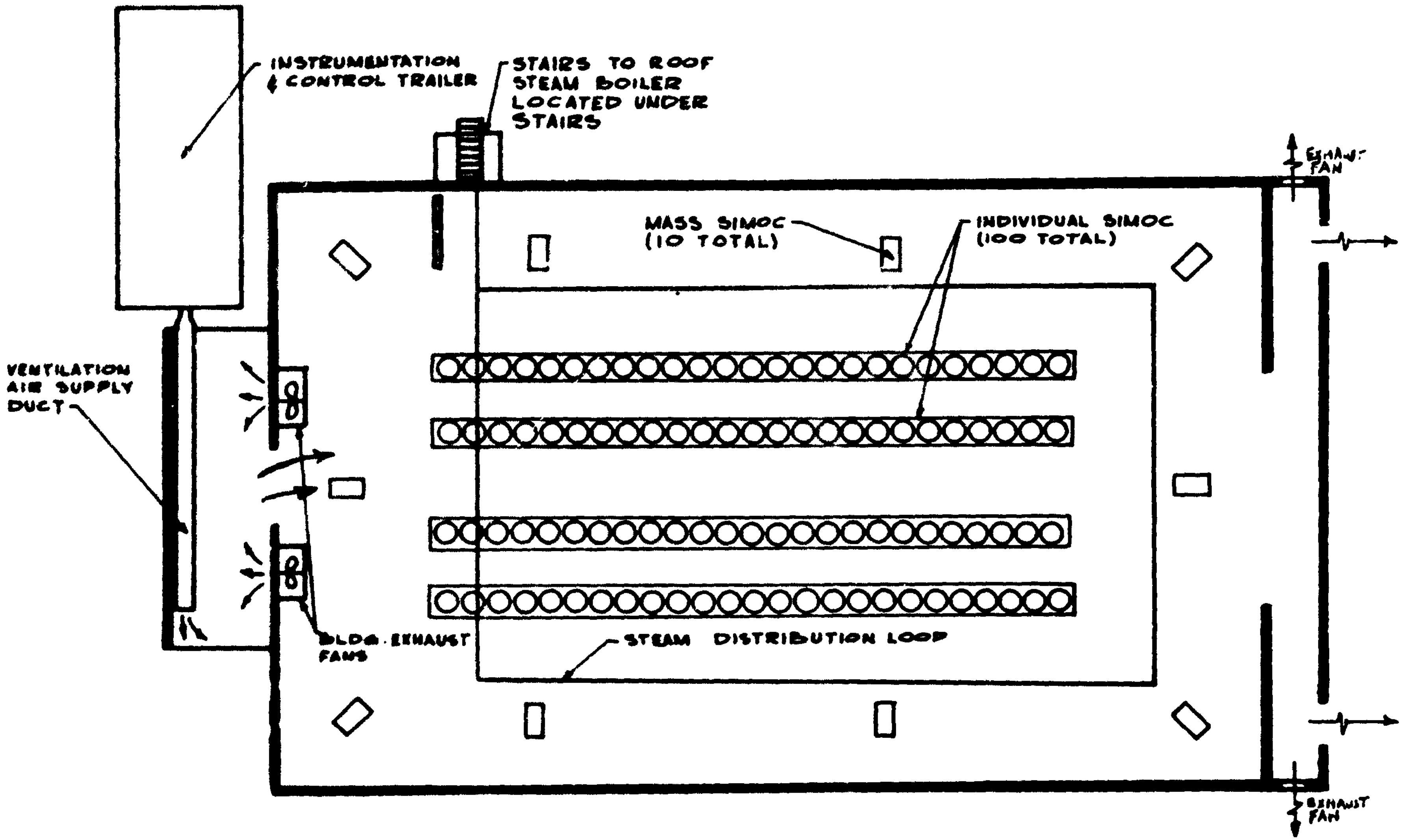


Figure 2.7 Plan of test shelter with simoc locations and equipment.

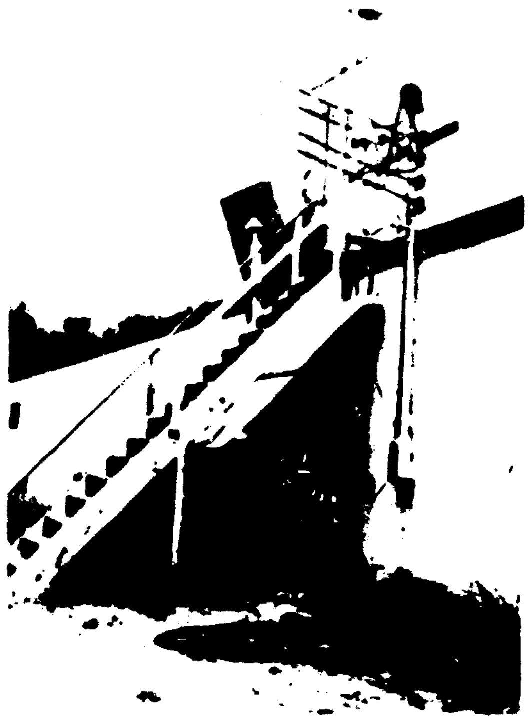


Figure 2.8 Steam boiler installation (under stairs) and water storage tanks on roof of test shelter.

Figure 2.9 Operators cab in Environmental Control and Instrumentation Trailer. Shown are instrumentation for control of trailer and recording test data.

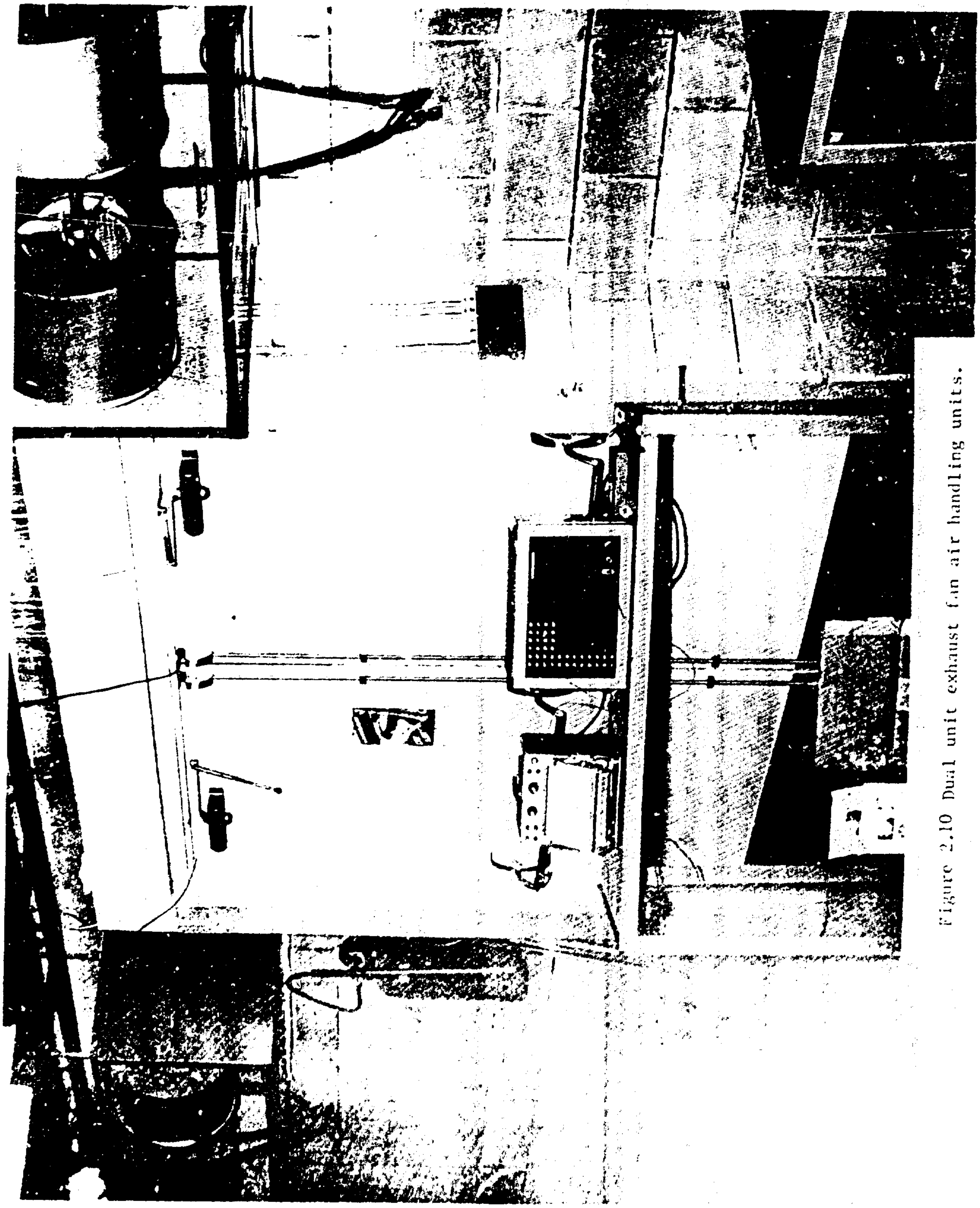


Figure 2.10 Dual unit exhaust fan air handling units.

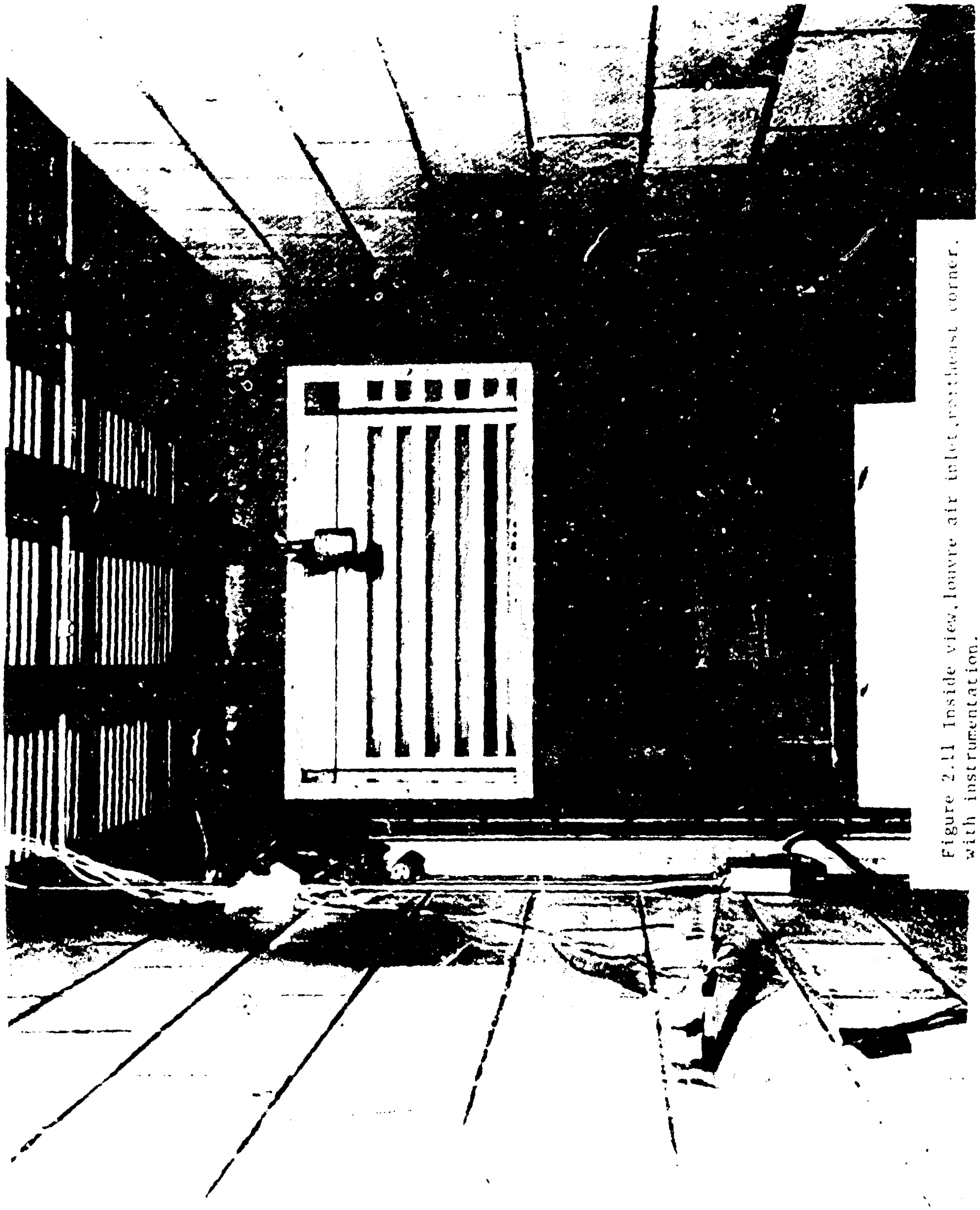


Figure 2.11 Inside view, louvre air inlet, northeast corner, with instrumentation.

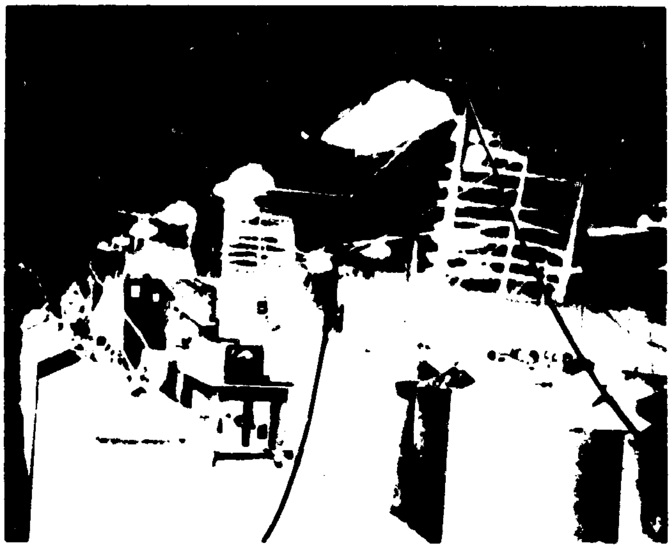


Figure 2.12 Punkahs (3ft length) in operation.

CHAPTER 3

DISCUSSION AND RESULTS

3.1 PHASE I OPTIMUM VENTILATION RATE

Initially, with a ventilation rate of 15 cfm per occupant and supply air simulating the Washington, D. C. 10% summer design day, a maximum 24-hour average shelter effective temperature of 81.1 was observed. This occurred over a period of four days with actual outdoor ambient conditions exceeding the 10% design day. The shelter occupant loading rate was 10 square feet per person.

Since an 81.1 ET was less than the established 82 ET upper limit, the air flow rate was decreased to 12 cfm and the shelter was allowed to stabilize in temperature. This process was repeated until steady state conditions were obtained with an average shelter effective temperature of 82 over a 24-hour period. The time intervals and the variation of the air flow rates are shown in Table 3.1. Figures 3.1 thru 3.8 show the outside temperature conditions and those observed at various points within the shelter itself.

Table 3.1

Optimum Ventilation Rate Test

Air Flow Rate cfm/occupant	Duration Days
Test 1 - 15	4
Test 2 - 12	5
Test 3 - 13.5	2
Test 4 - 14	3
Test 5 - 15	2

The slow temperature response of the shelter to the varying air flow rates, indicated by Table 3.1, was due primarily to the great mass of the structure which absorbed or dissipated large quantities of heat before reaching thermal equilibrium. An average effective temperature of 82.1 was calculated for the last day of this phase at which time outdoor conditions were very close to the 10% design day (see plot for August 23 on Figure 3.1). By the end of the "optimum shelter ventilation rate test" (Phase I), the building had been occupied for 14 days and the wall, floor, and ceiling temperatureswere stable or uniformly cyclic. The air flow rate at this time was 15 cfm per occupant, or 7200 cfm total, which is the rated capacity of the installed shelter ventilation system.

3.2 PHASE II OVERCROWDING - EFFECTIVE TEMPERATURES

With the ventilation rate established at 15 cfm per occupant, the effects of overcrowding were observed. The shelter population was increased to 640 occupants (a loading rate of 7.5 sq ft per person) compared to the 480 person (10 sq ft per person) design capacity. After eight days under these conditions, the wall, floor and ceiling temperatures were well stabilized and the shelter effective temperature curve substantially repeated itself during the last two 24-hour periods. The average shelter effective temperatures recorded, for these two days, were 83.3 and 83.1. The maximum effective temperatures recorded during the same period were 84.6 and 84.8. Effective temperatures in excess of 84 were noted for about 5 consecutive hours around

noon for each of these days. Also effective temperatures over 82 occurred for 80% to 90% of the time.

3.3 PHASE III AIR DISTRIBUTION PATTERNS

The pictorial representations of air flow patterns in Appendix D indicate clearly the capability of the punkahs to alter the air distribution patterns in the shelter. The flow pattern of 6 September, in which punkahs were not used, shows the predictable pattern, i.e., a north-south flow and generally upwards towards the exhaust fans. Large "dead" areas in the vicinity of the exhaust fans can be noted on the diagrams. The unsymmetrical pattern at the 5 foot level is due to an electric switch panel, about 4 ft x 8 ft mounted 4 feet above the fl``r, which acted as a baffle deflecting the air. At the one foot level, a 3 inch pipe sleeve space in the west wall was inadvertently left open resulting in a jet of outside air at this location. In addition, the exhaust fans on the west side of the shelter operated at 940 rpm compared to 890 rpm for fans on the east side, due to difference in motor power outputs.

The test pattern for September 6, in which a clockwise flow was created transverse to the main flow path, shows the ability of the punkahs to force the air into poorly ventilated areas. Also, downward flows of the air were detected, at the 5 foot level, resulting in mixing and disruption of the stratifying tendency prevalent in inadequately ventilated spaces.

When the punkahs were moving air in the same general direction as the prevailing flow, there were no significant differences in

distribution patterns between the punkah and non-punkah patterns, particularly in the test of 9 September where the four punkahs were in line. The flow patterns indicate that, with more punkahs, it would be possible to direct the air into virtually any pattern desired. Thus, equitable distribution of the available ventilation could be obtained without ductwork and with negligible power input required.

An increase in air velocity magnitudes, in the general area of the punkahs, is an additional beneficial effect, contributing to the comfort index factor, by inducing a greater rate of evaporation of moisture from the skin.

Previous work conducted at the PSDC[8] indicated power requirements for a punkah to be about 0.01 horsepower. This low power requirement is due primarily to the punkah's capability to move large quantities of air at relatively low velocities.

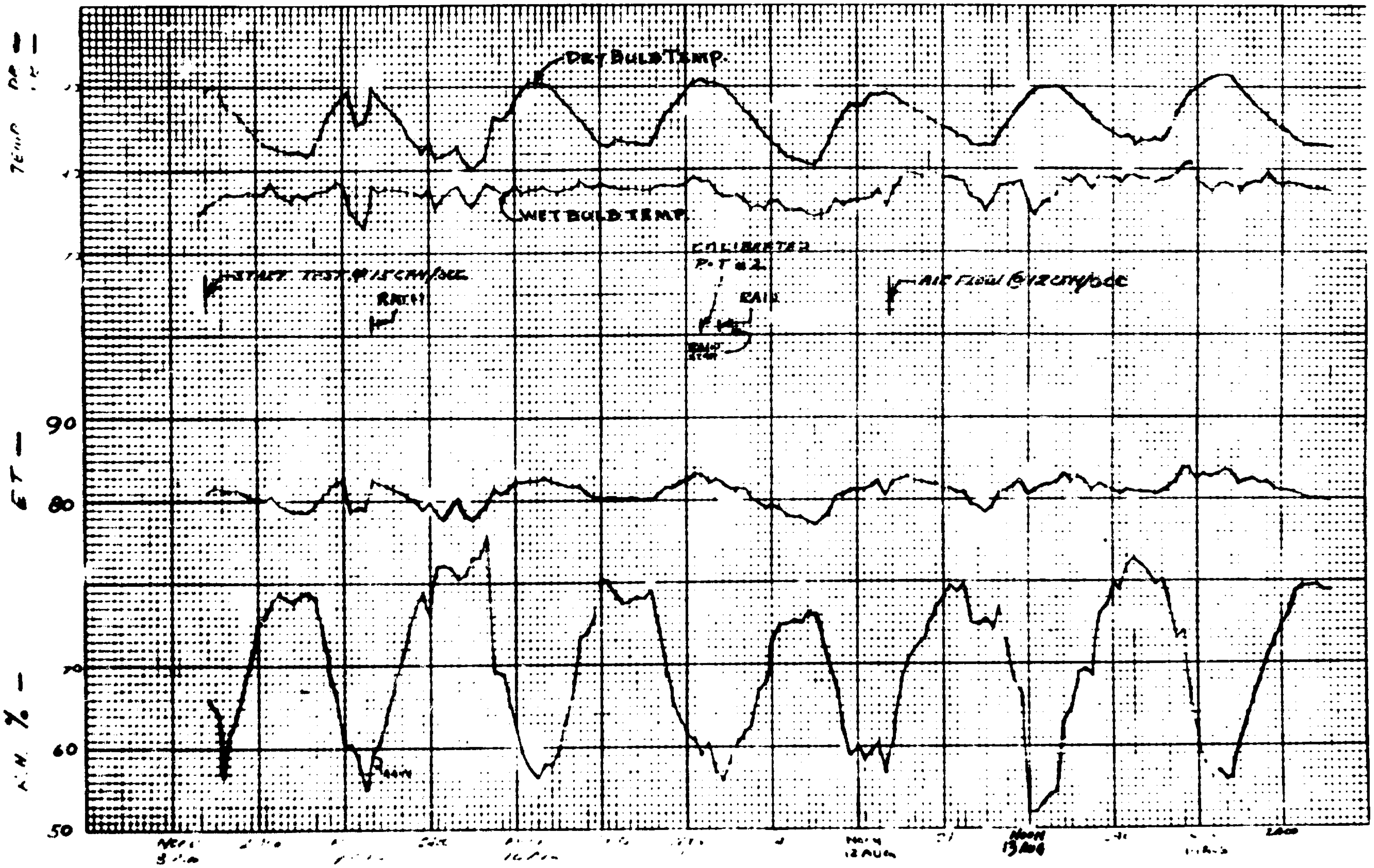


Figure 3.1 Shelter response, geometric center.

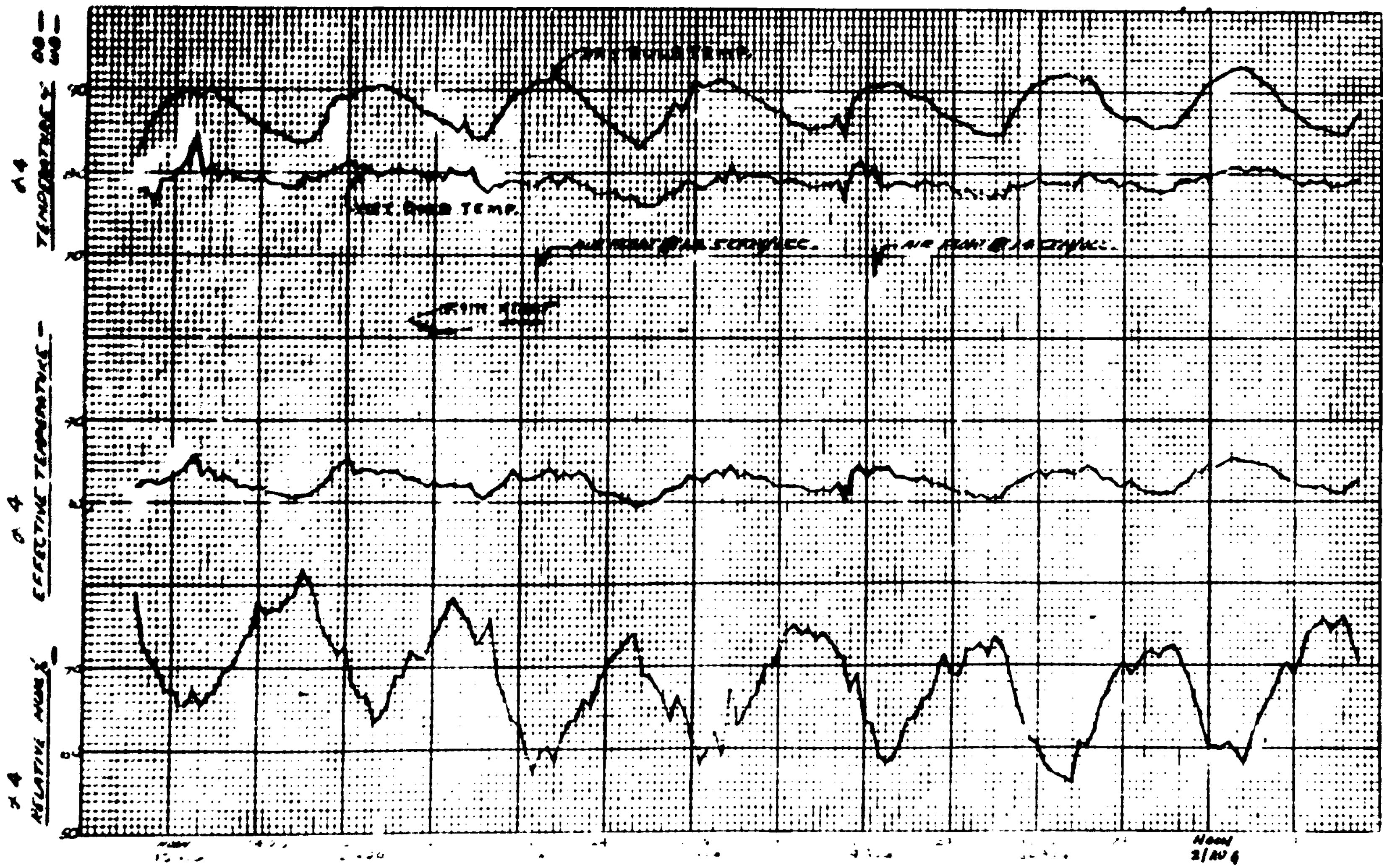


Figure 3.1 (cont'd). Shelter response, geometric center.

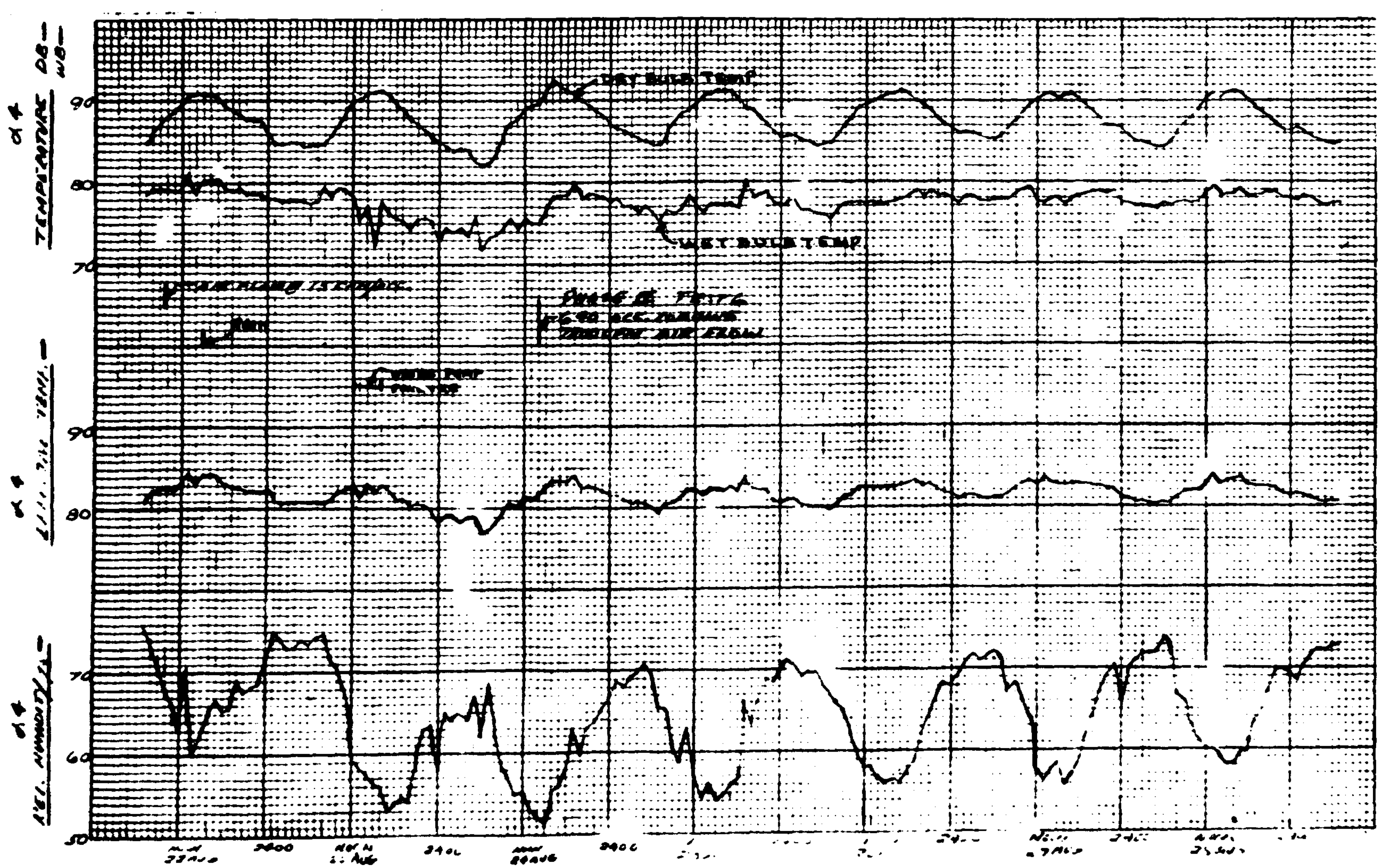


Figure 3.1 (cont'd). Shelter response, geometric center.

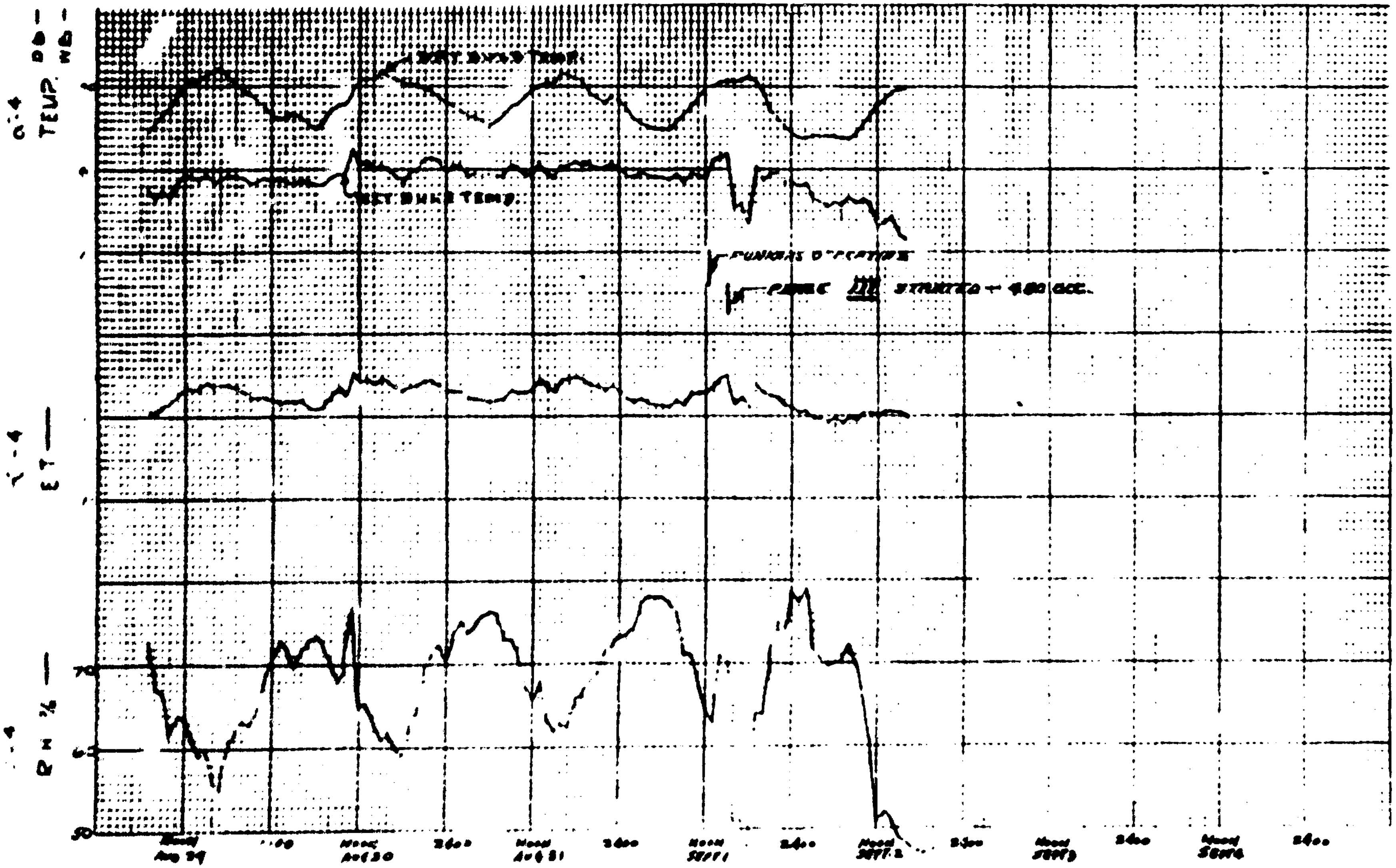


Figure 3.1 (cont'd). Shelter response, geometric center.

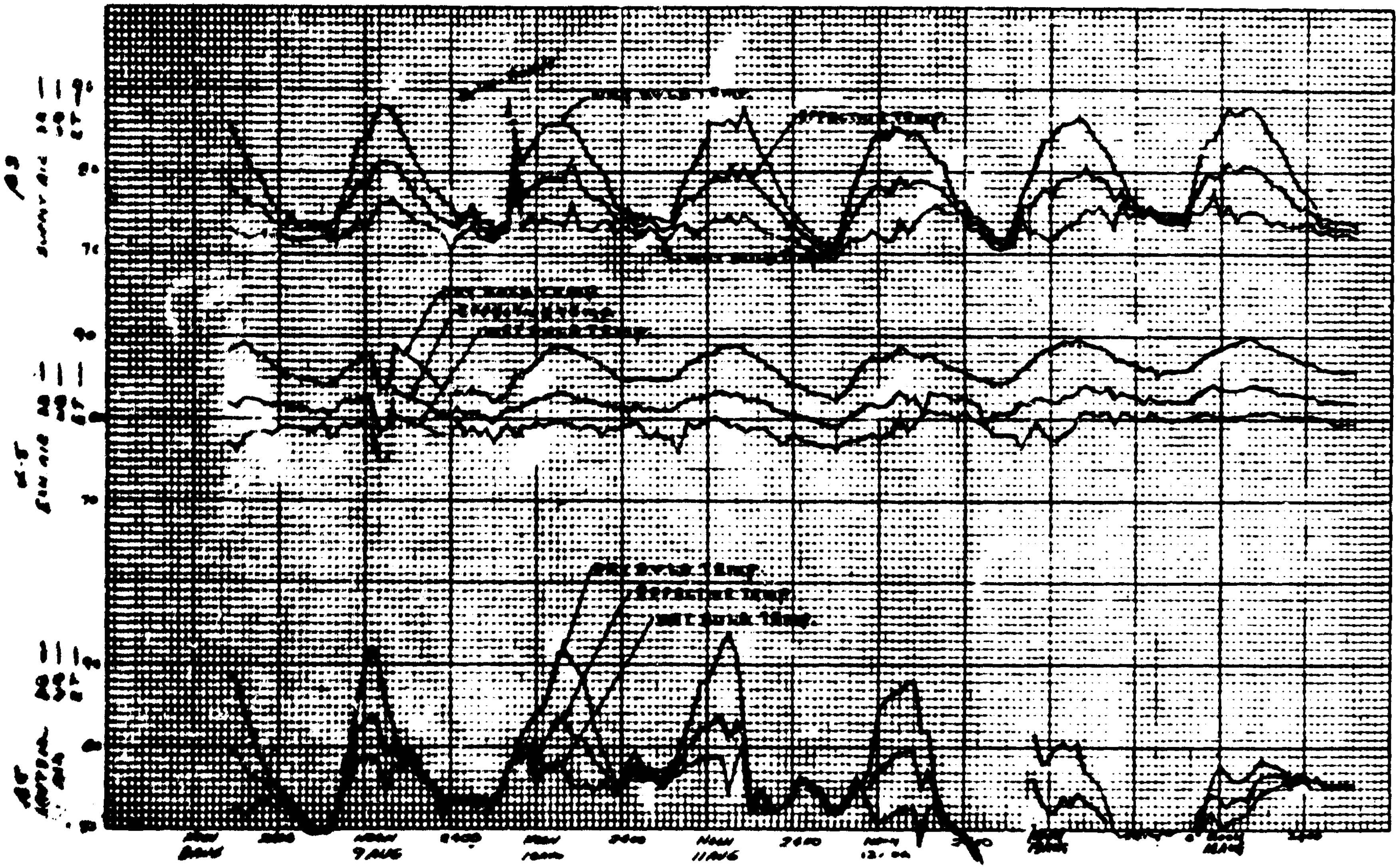


Figure 3.2 Supply, exhaust, and outside air conditions.

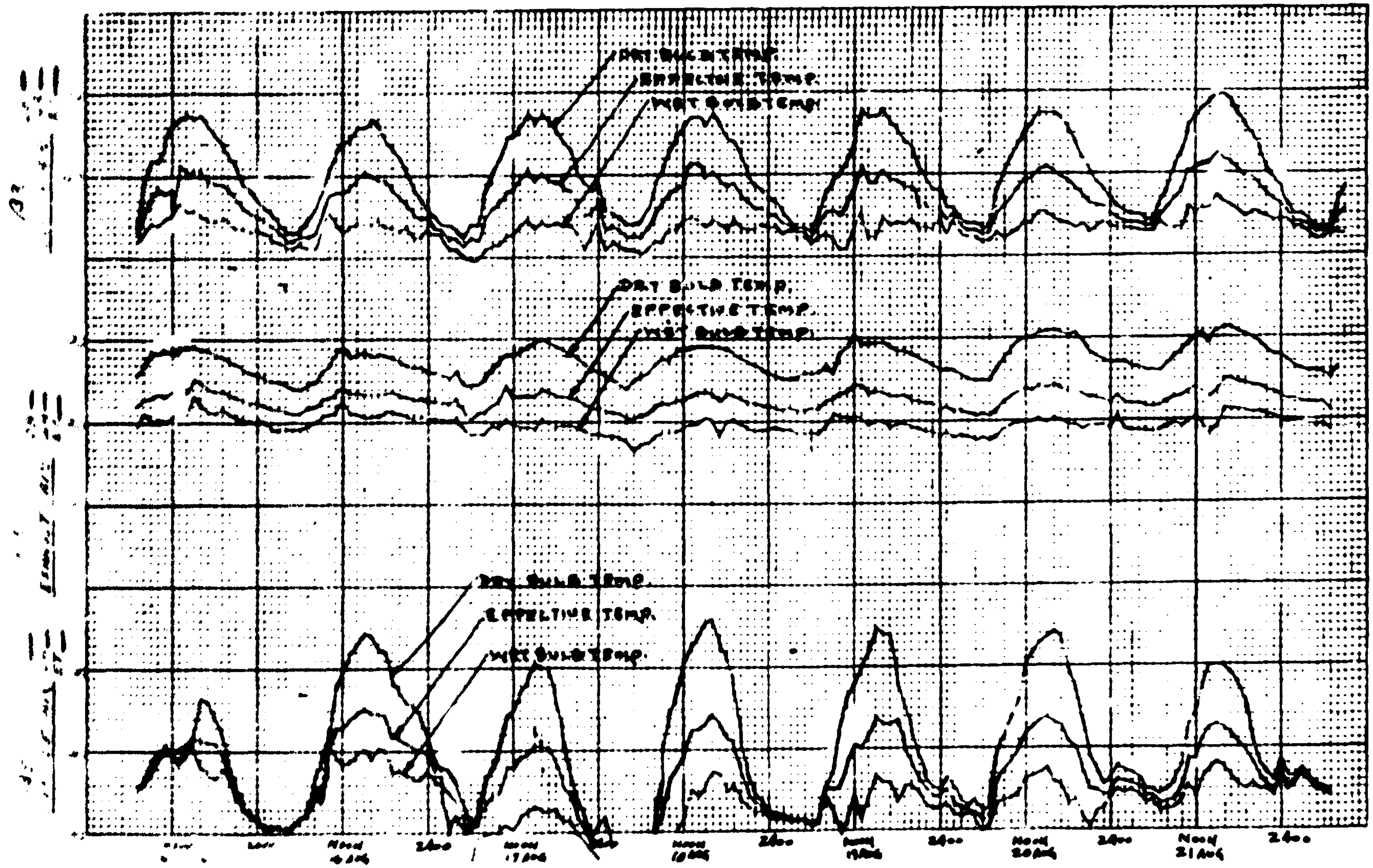


Figure 3.. (cont'd). Supply, exhaust, and outside air conditions.

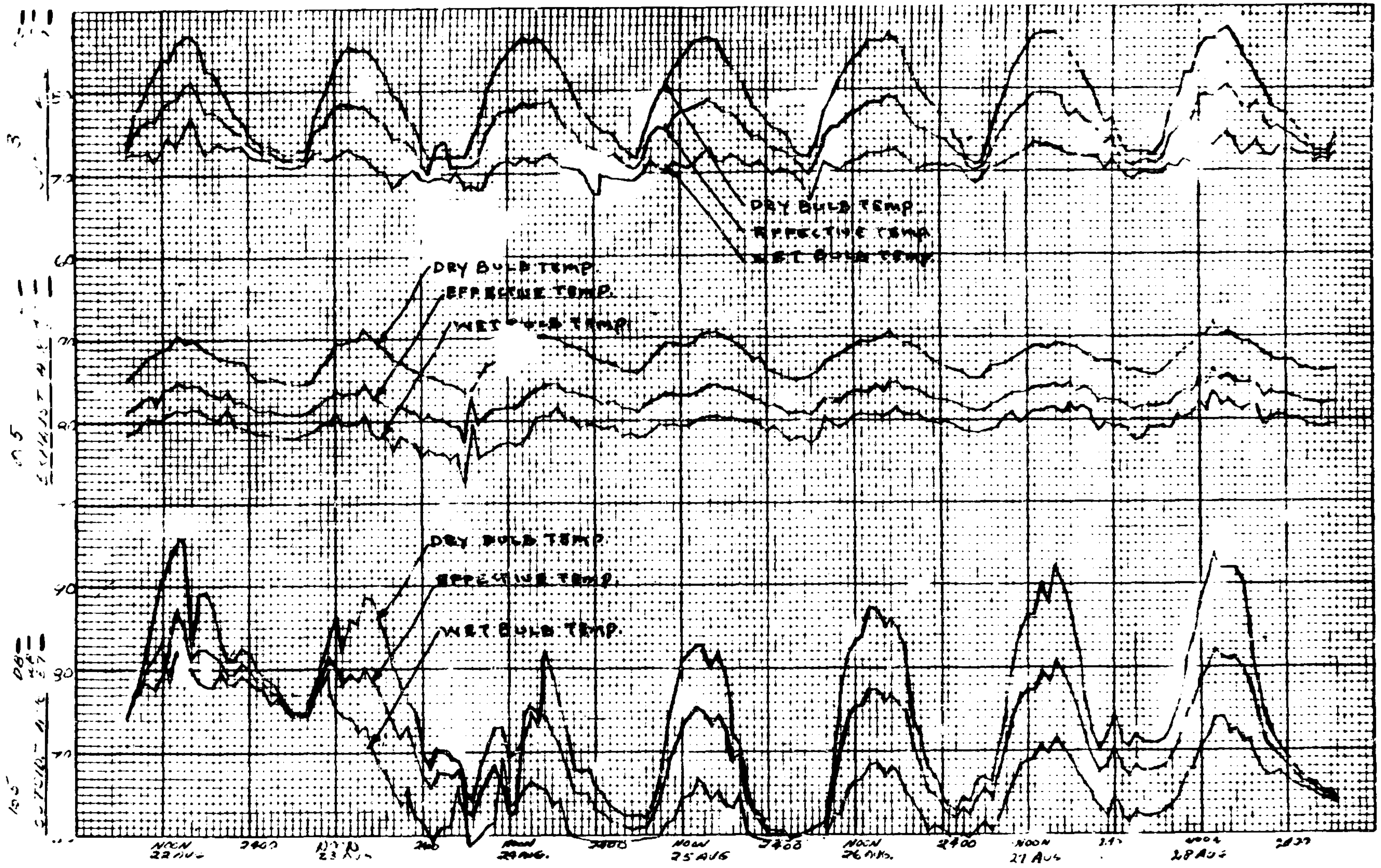


Figure 3.2 (cont'd). Supply, exhaust, and outside air conditions.

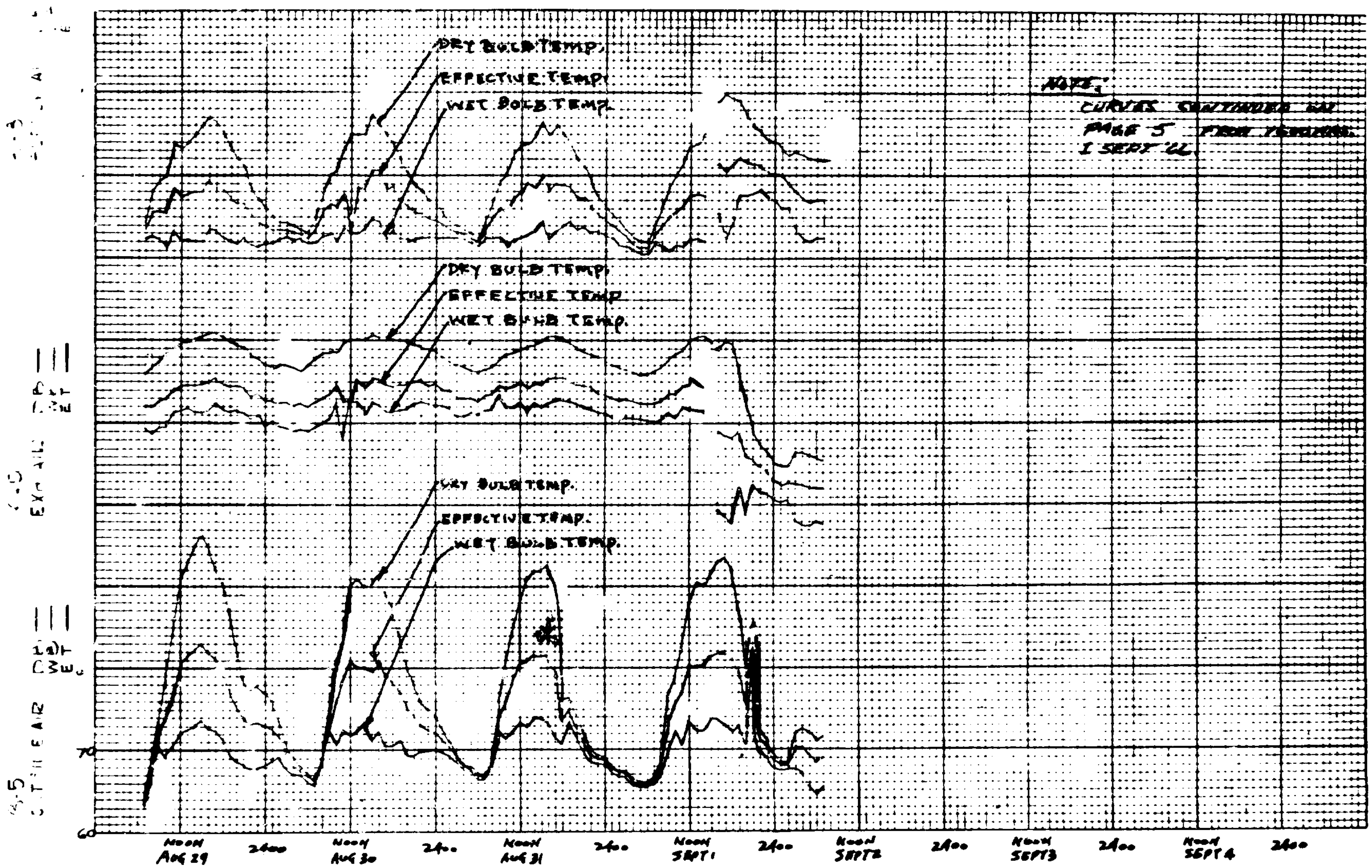


Figure 3.2 (cont'd). Supply, exhaust, and outside air conditions.

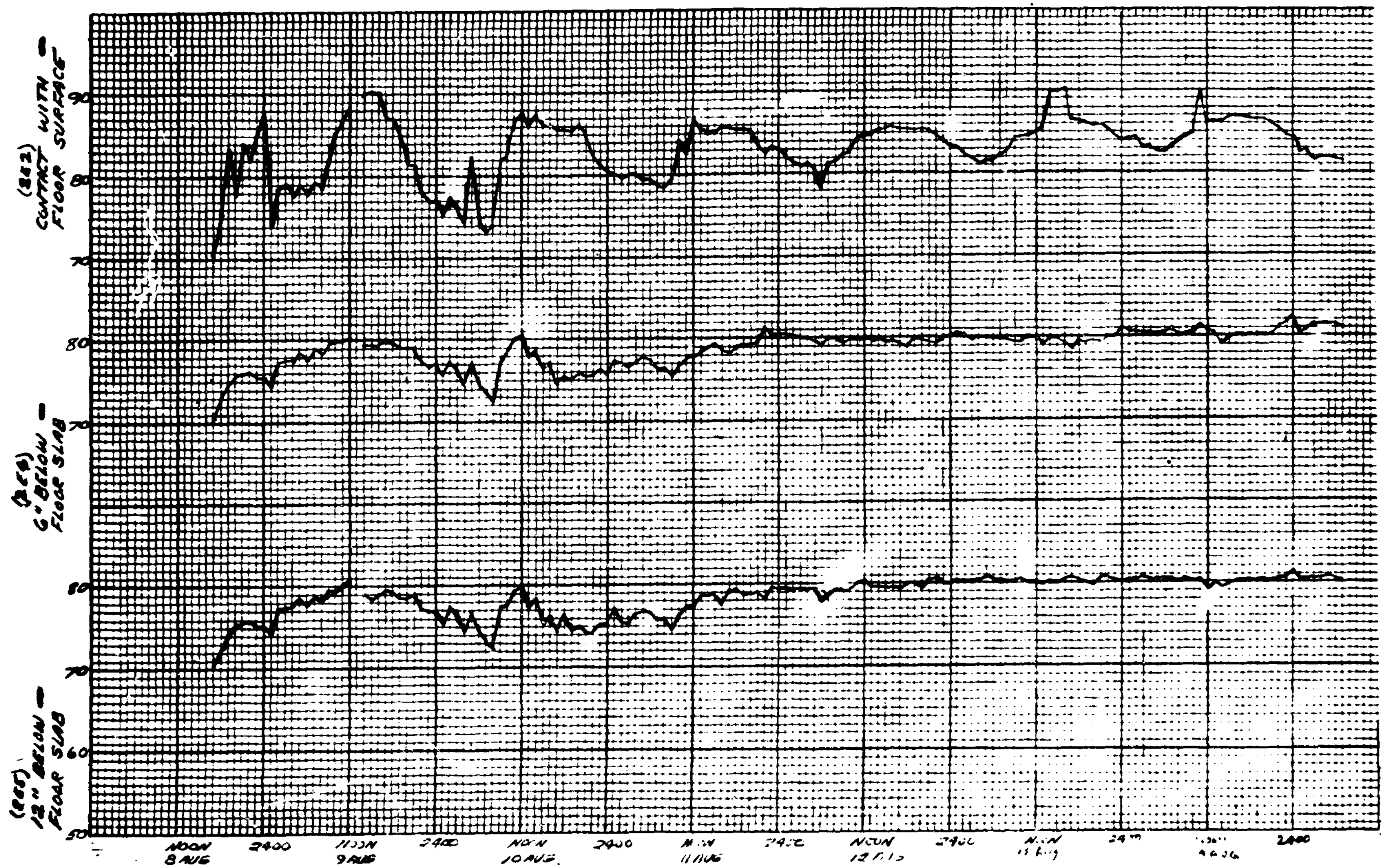


Figure 3.3 Floor temperatures, geometric center.

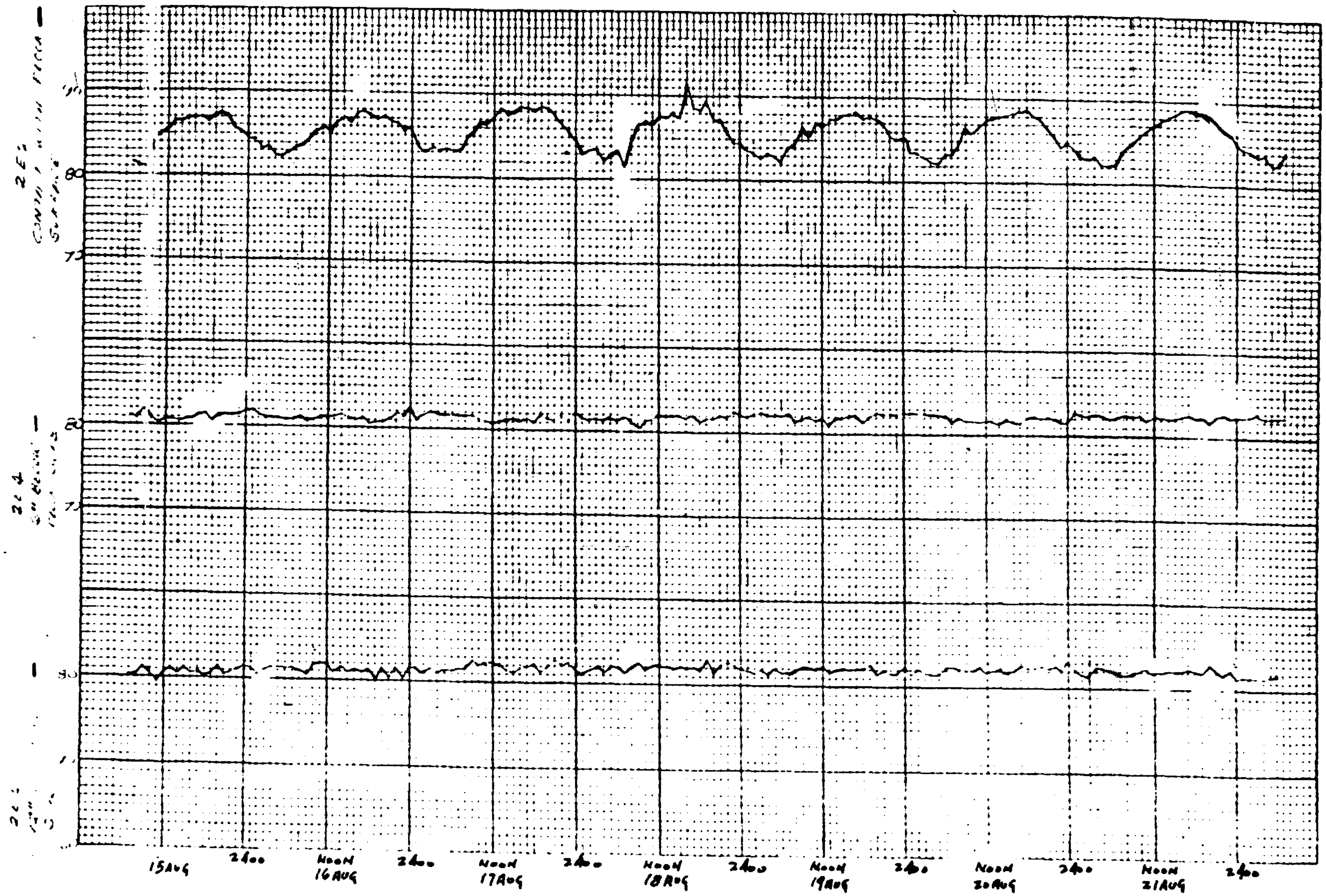


Figure 3.3 (cont'd). Floor temperatures, geometric center.

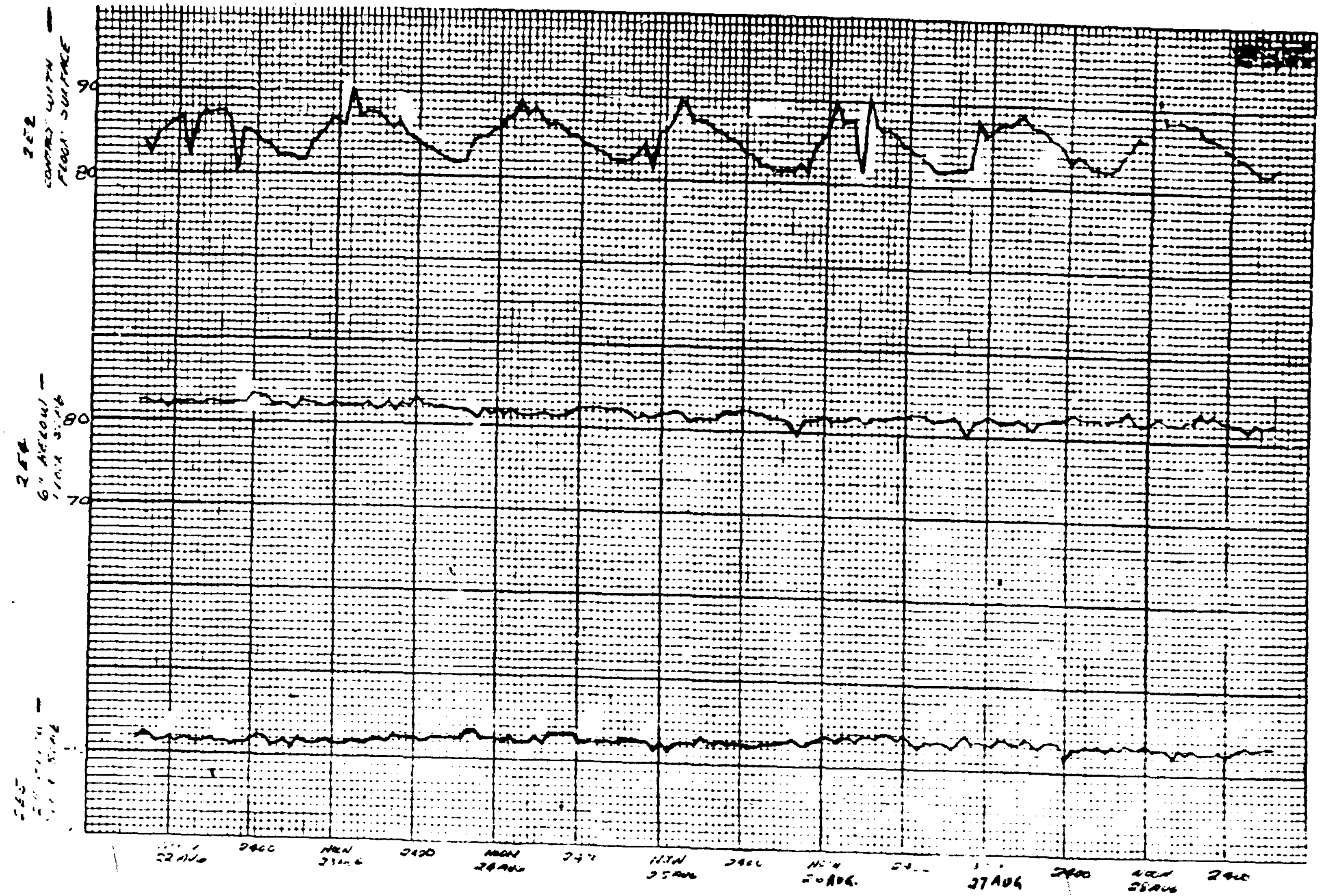


Figure 3.3 (cont'd). Floor temperatures, geometric center.

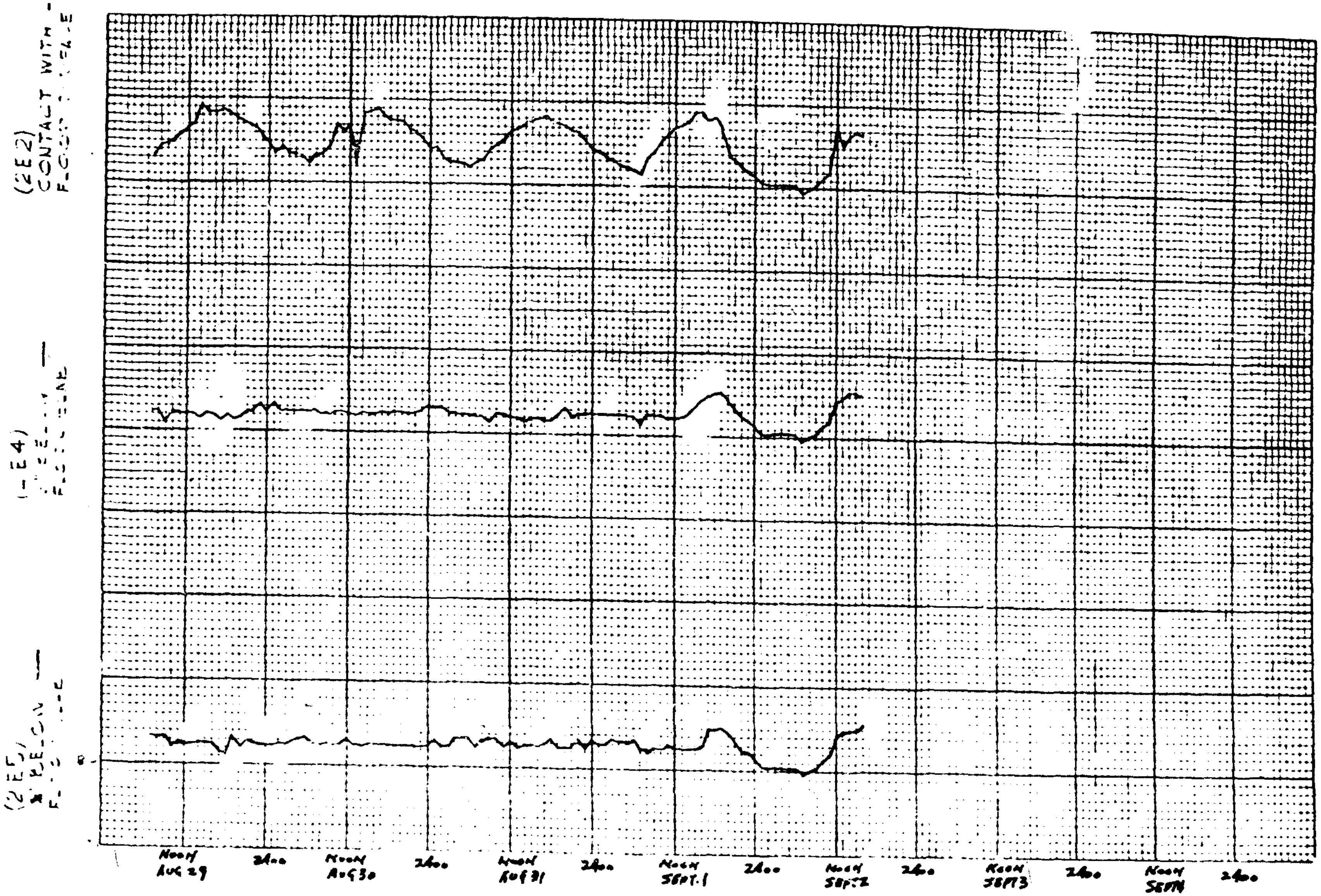


Figure 3.3 (cont'd). Floor temperatures, geometric center.

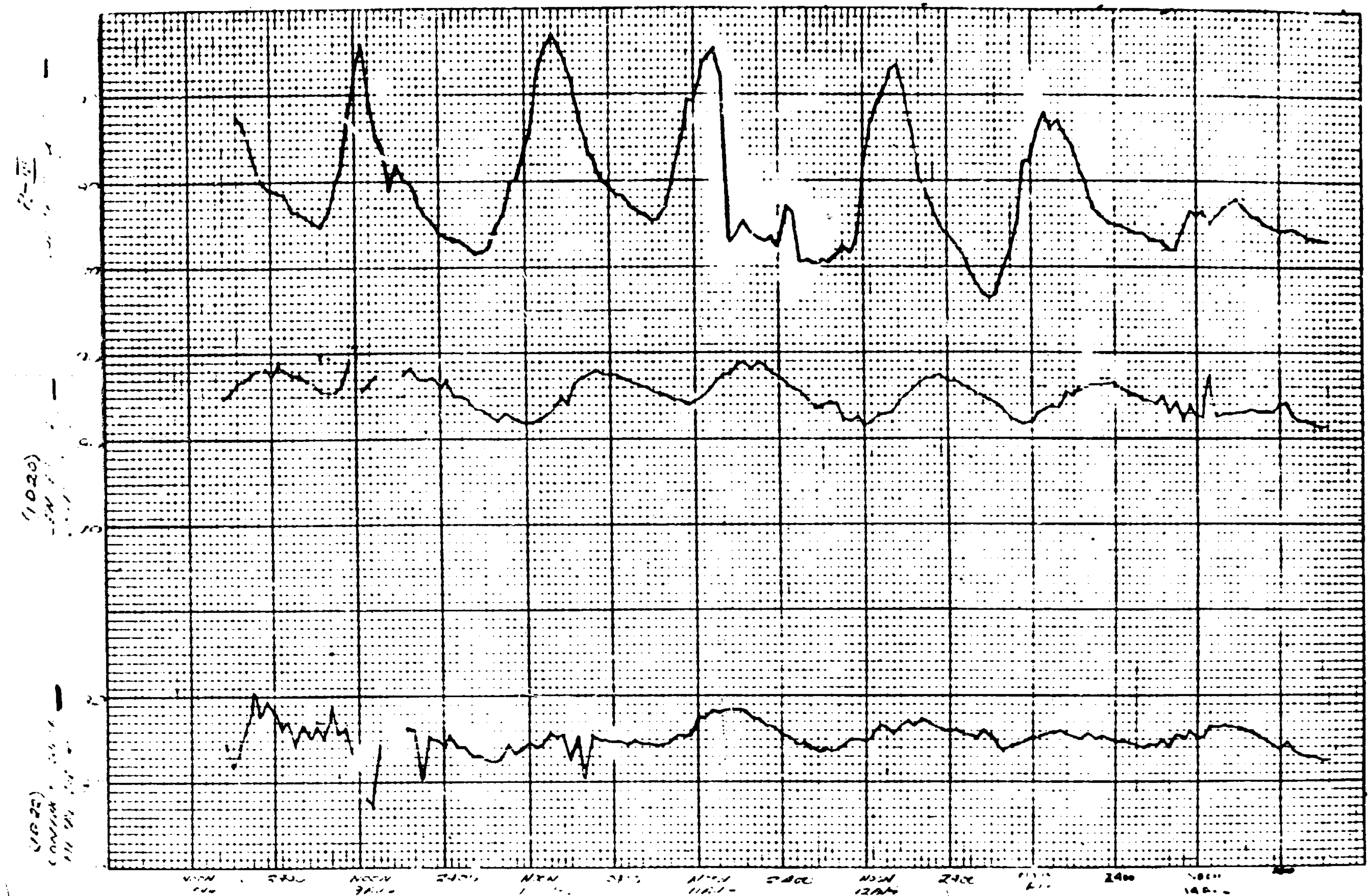


Figure 3.4 Roof temperatures, geometric center.

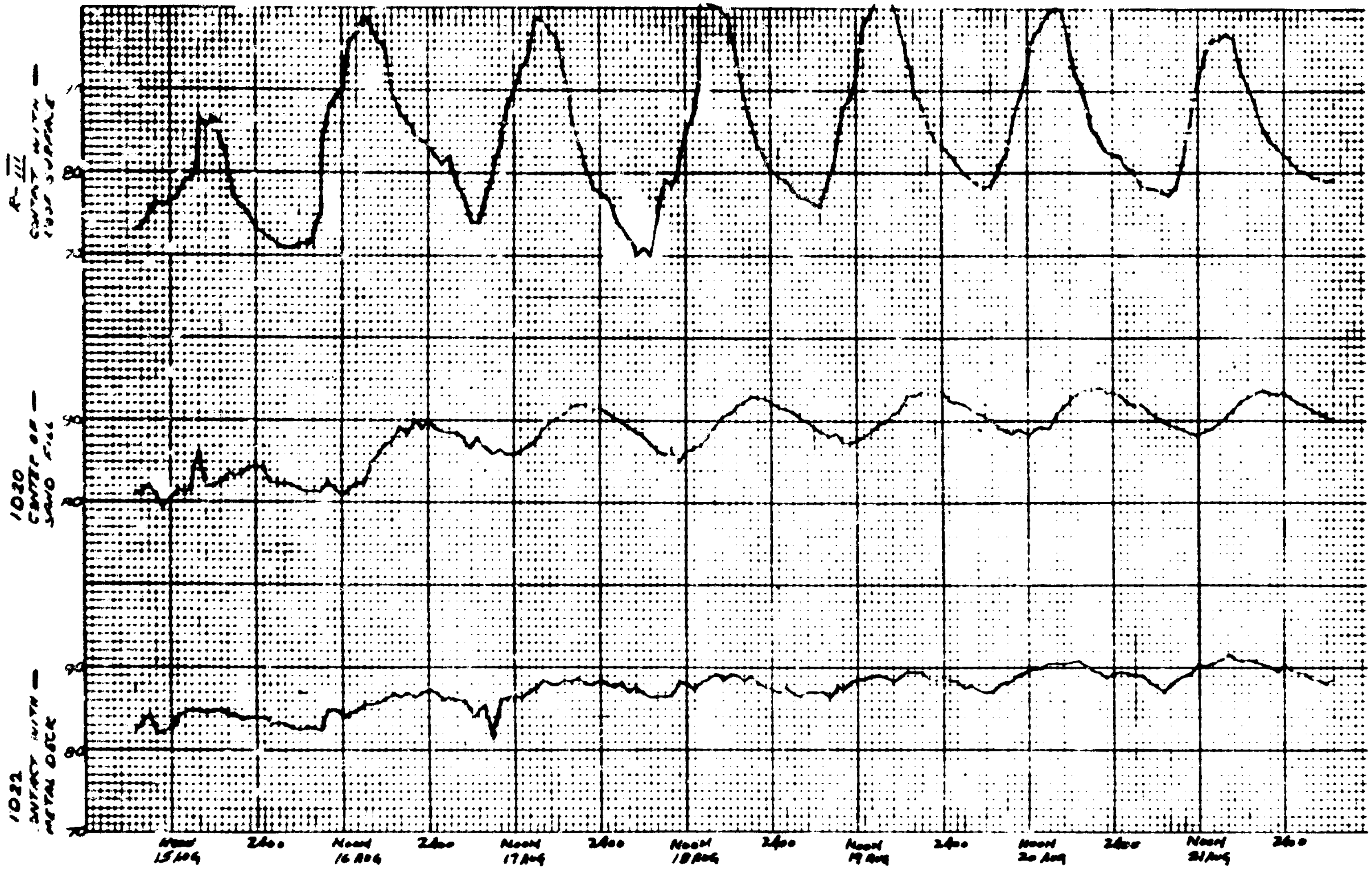


Figure 3.4 (Cont'd). Roof temperatures, geometric center.

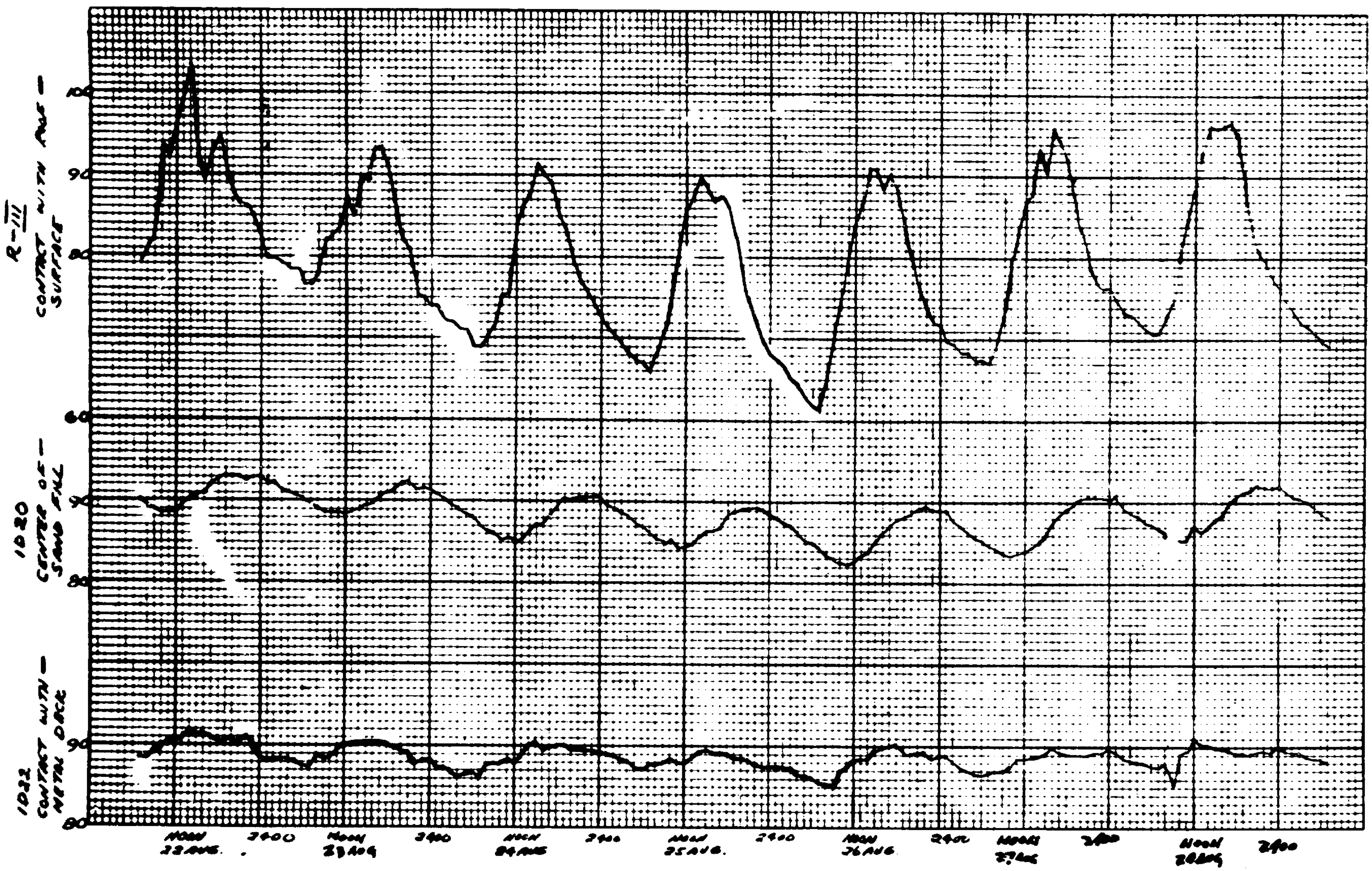


Figure 3.4 (cont'd). Roof temperatures, geometric center.

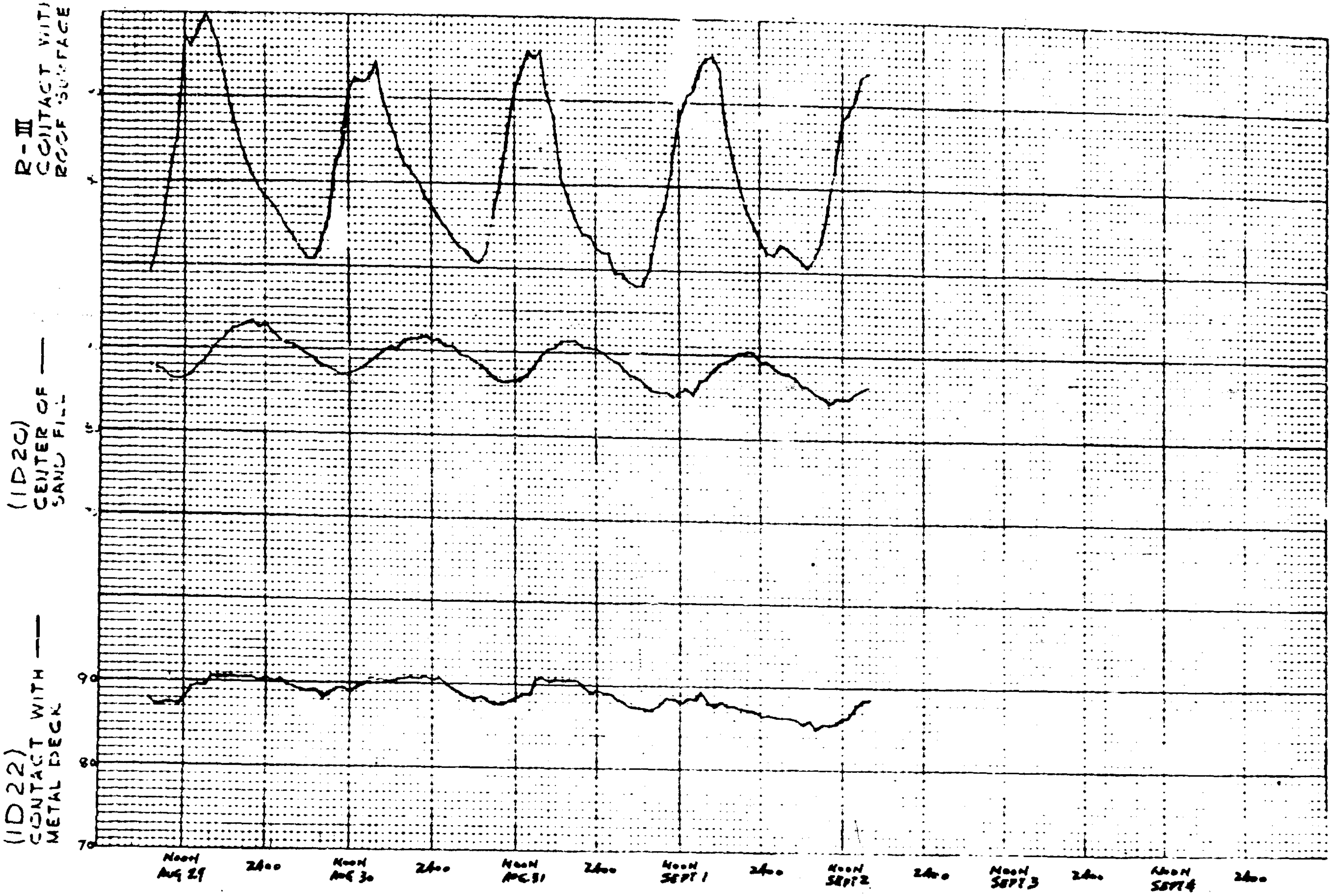


Figure 3.4 (cont'd). Roof temperatures, geometric center.

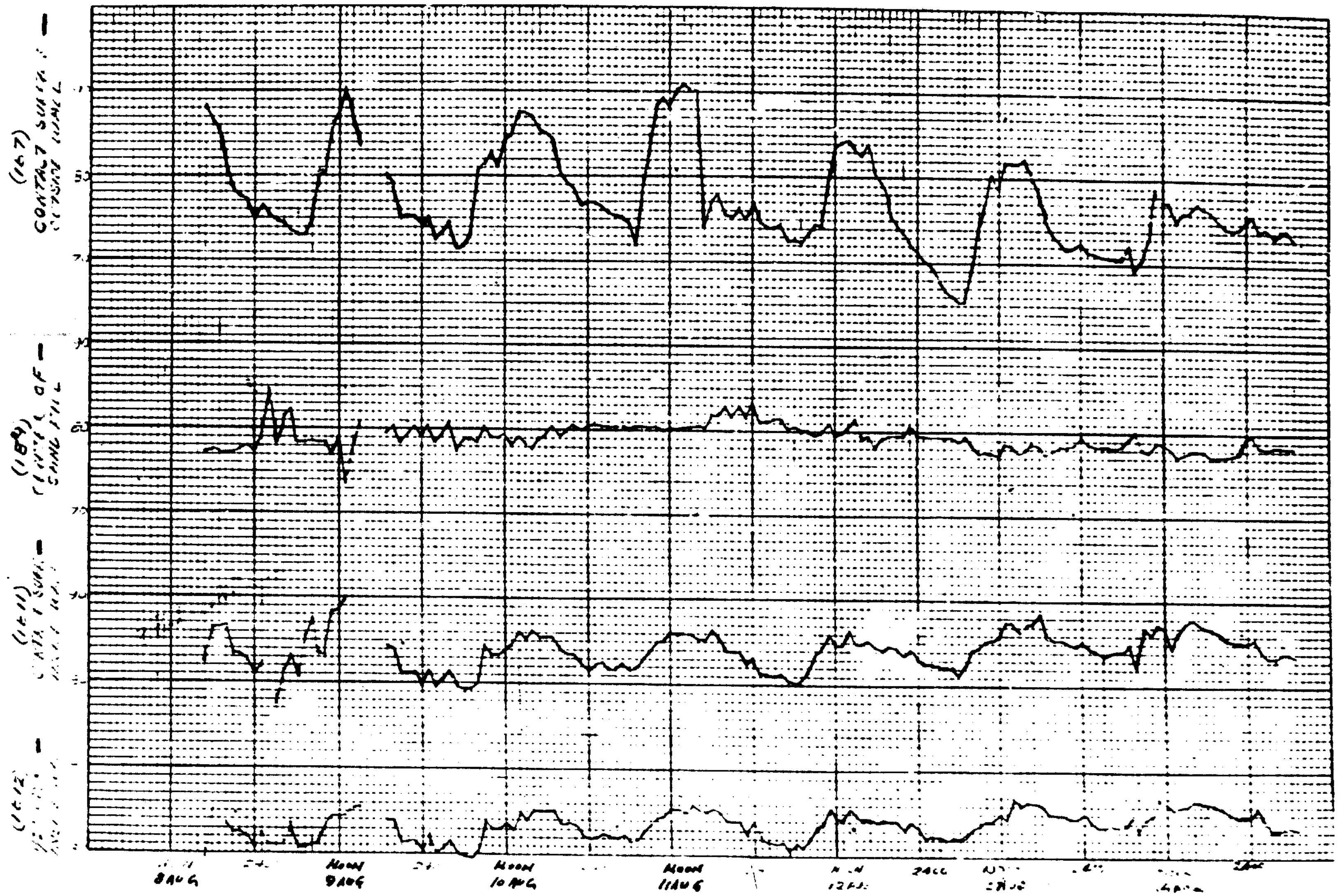


Figure 3.5 Wall temperatures, geometric center, north wall.

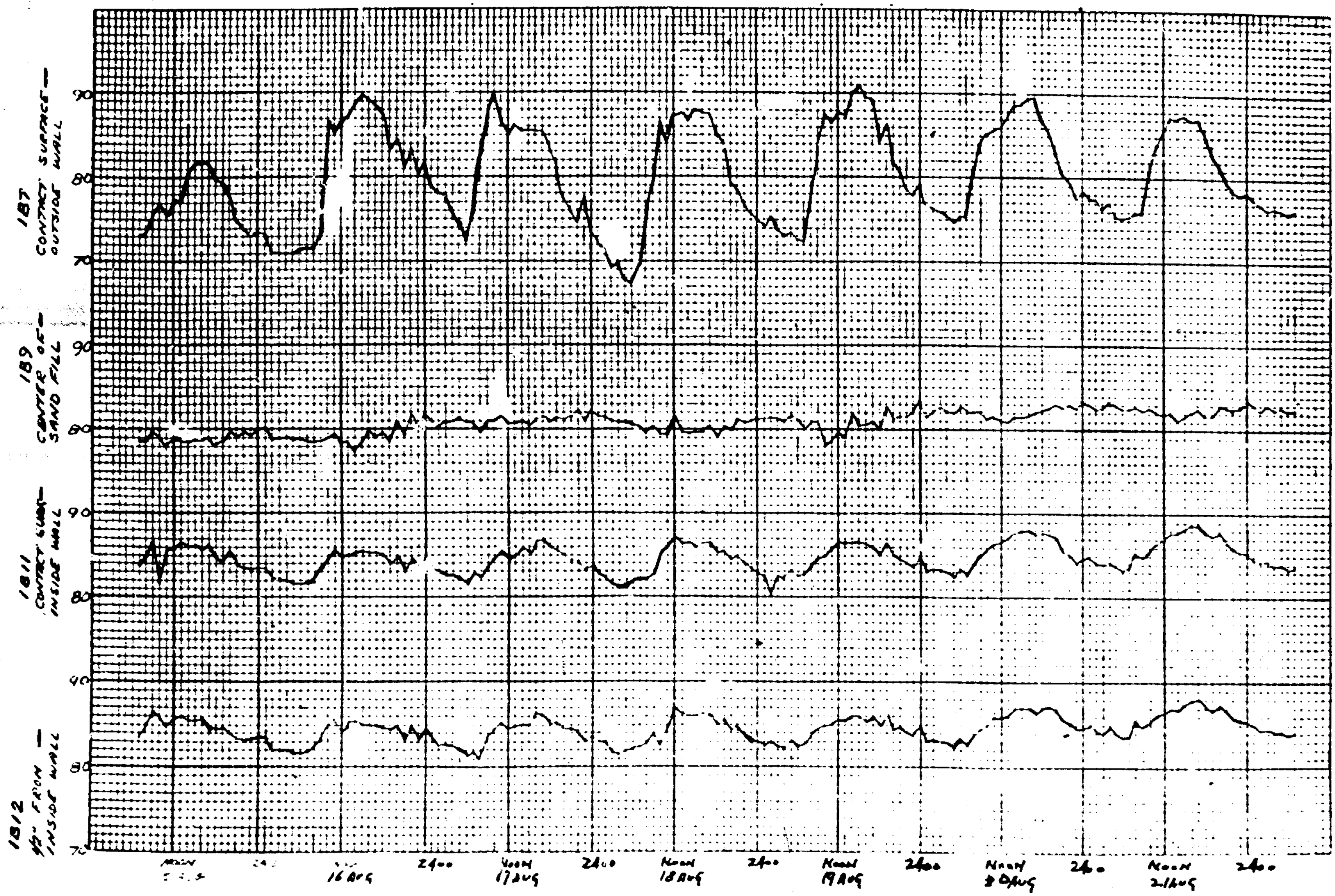
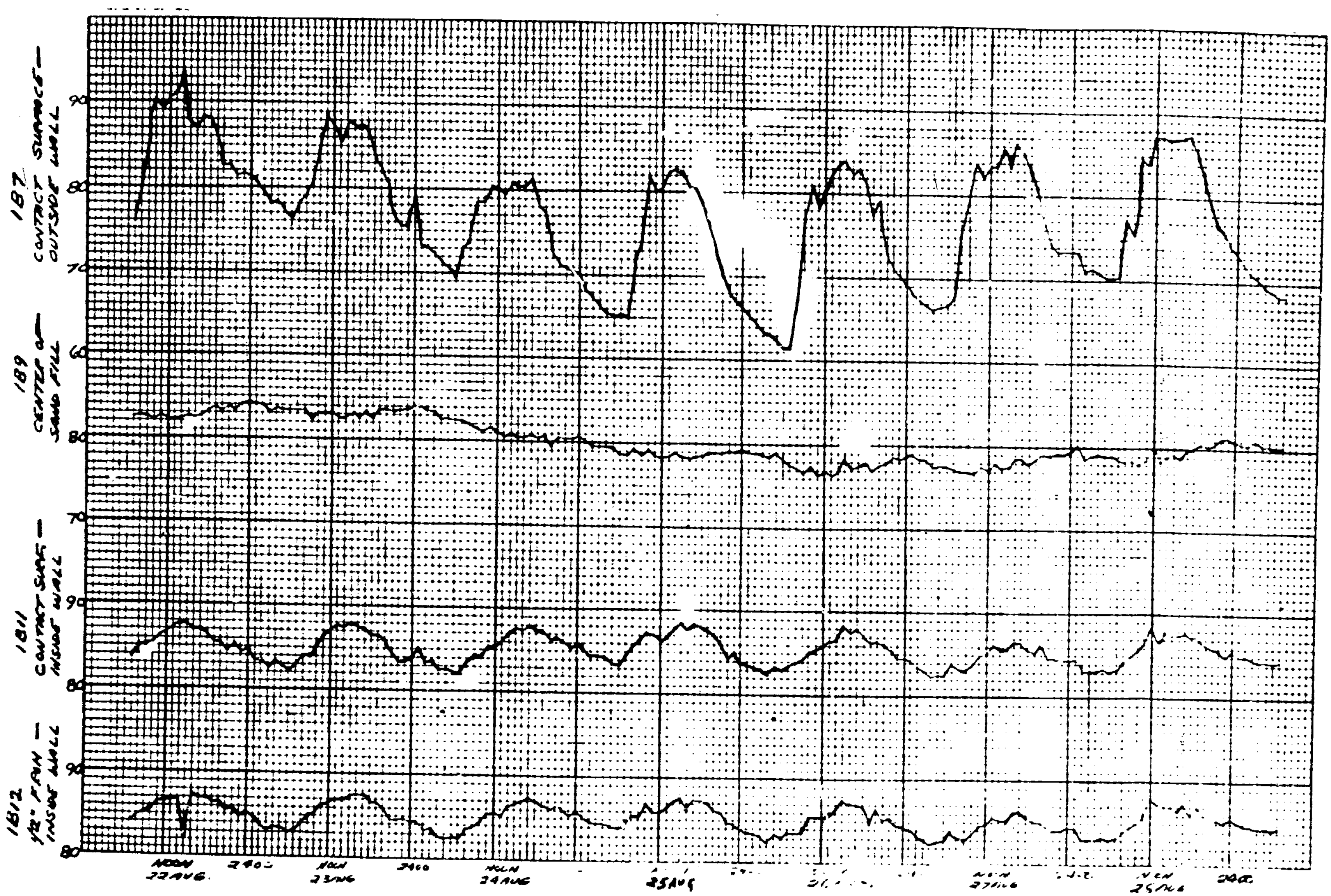


Figure .5 (cont'd). Wall temperatures, geometric center, north wall.



Figu 3.5 (cont'd). Wall temperatures, geometric center, north wall.

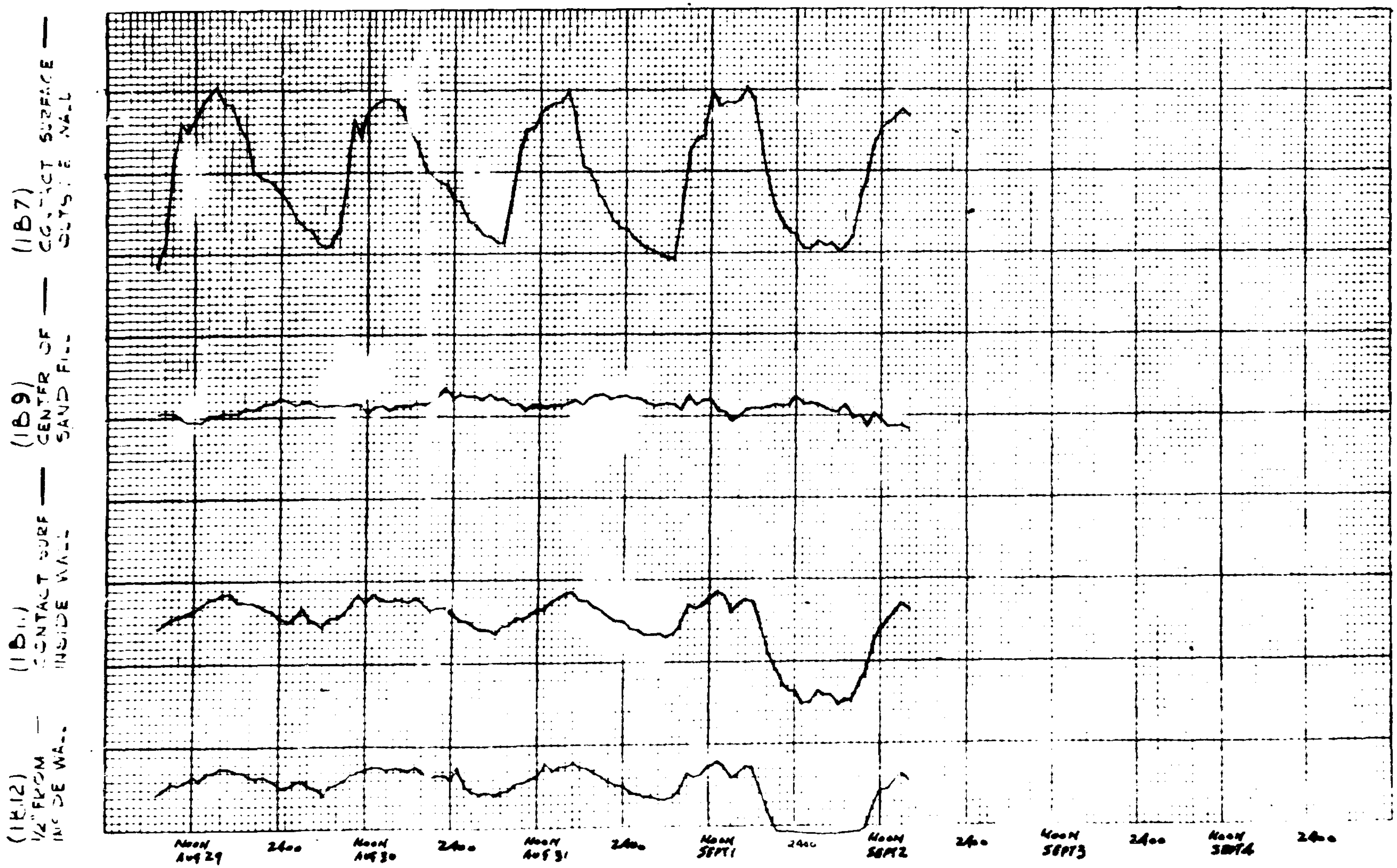
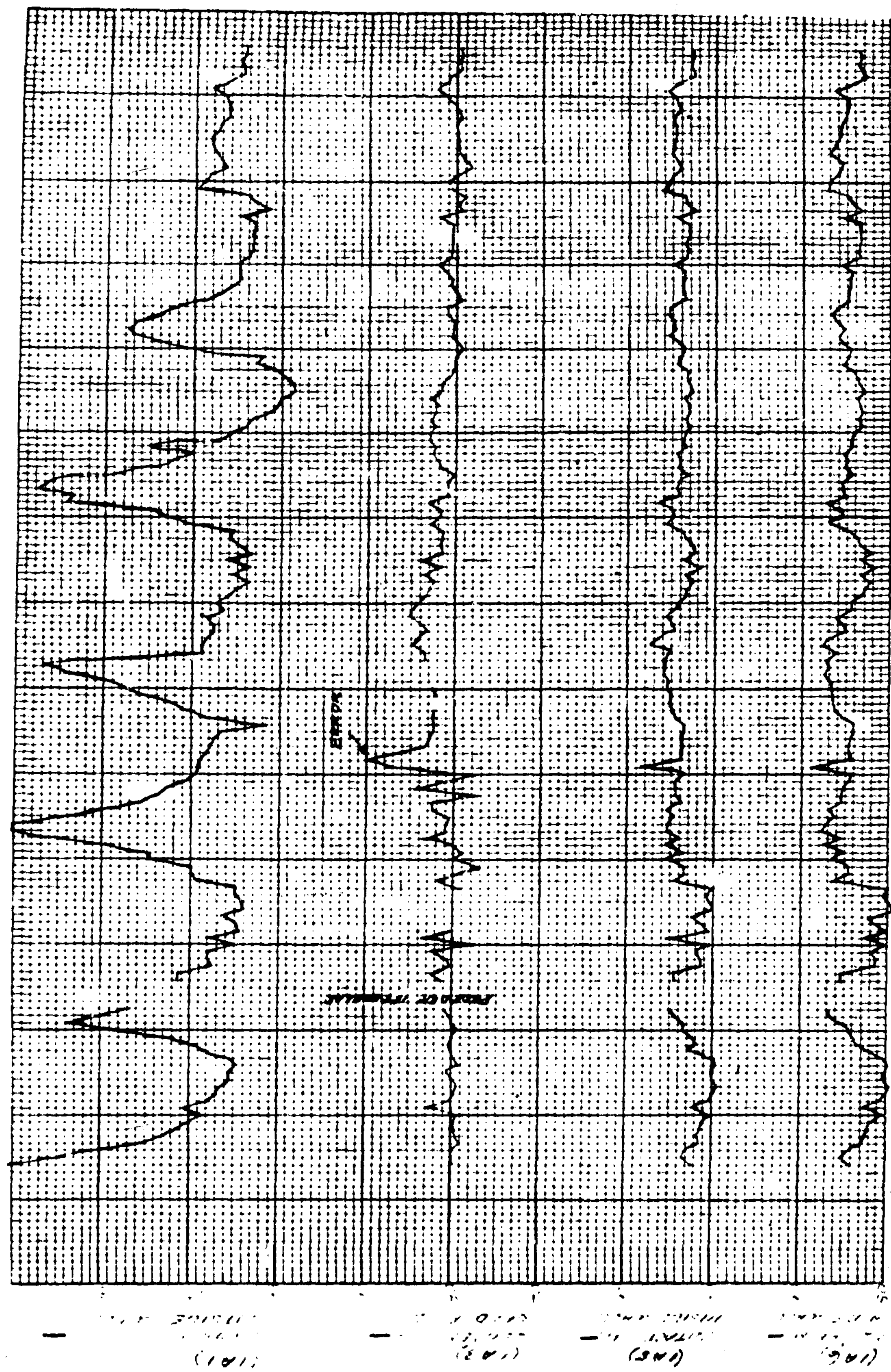


Figure 3.5 (con 'd). Wall temperatures, geometric center, north wall.



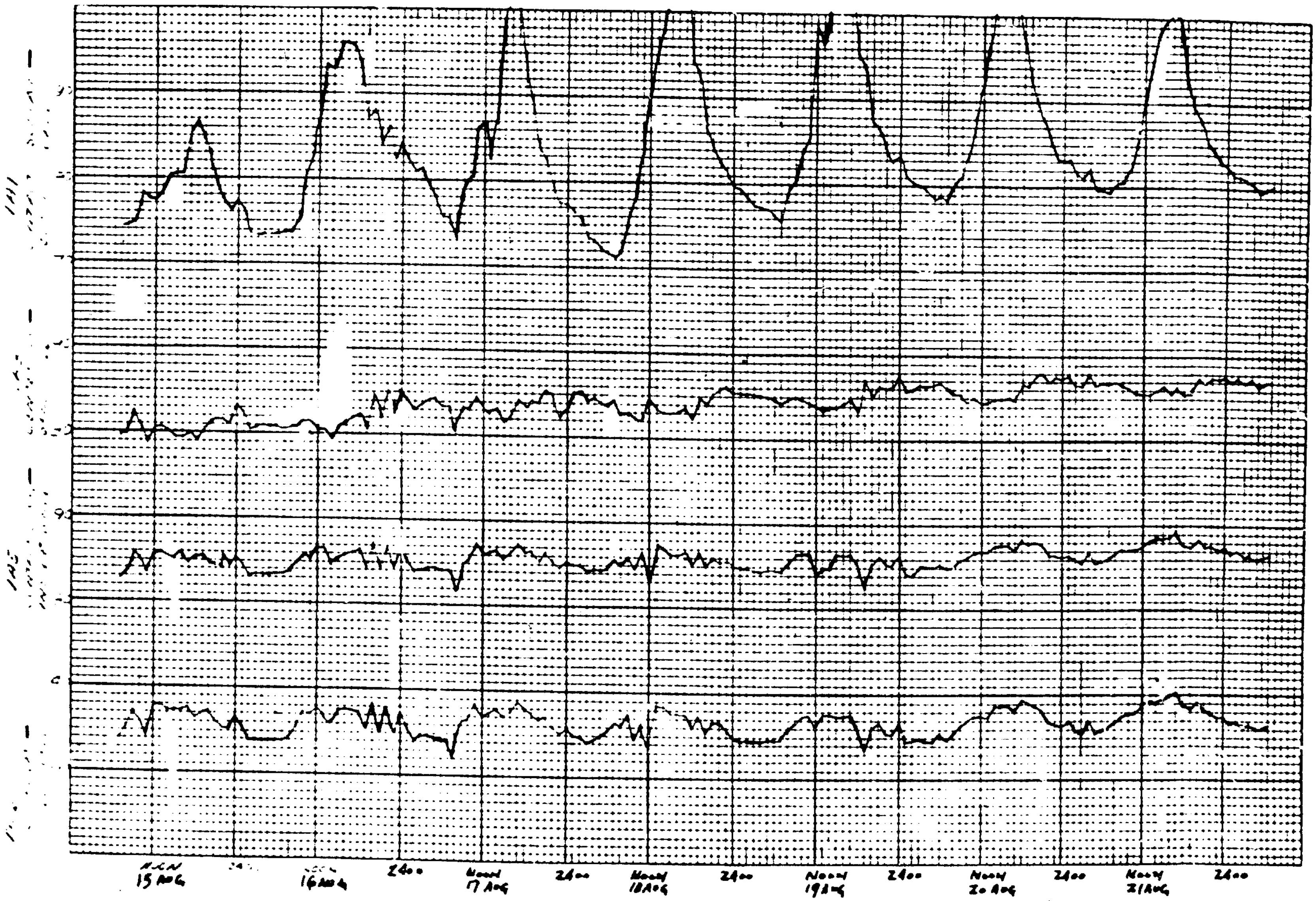


Figure 3.6 (cont'd). Wall temperatures, southeast wall.

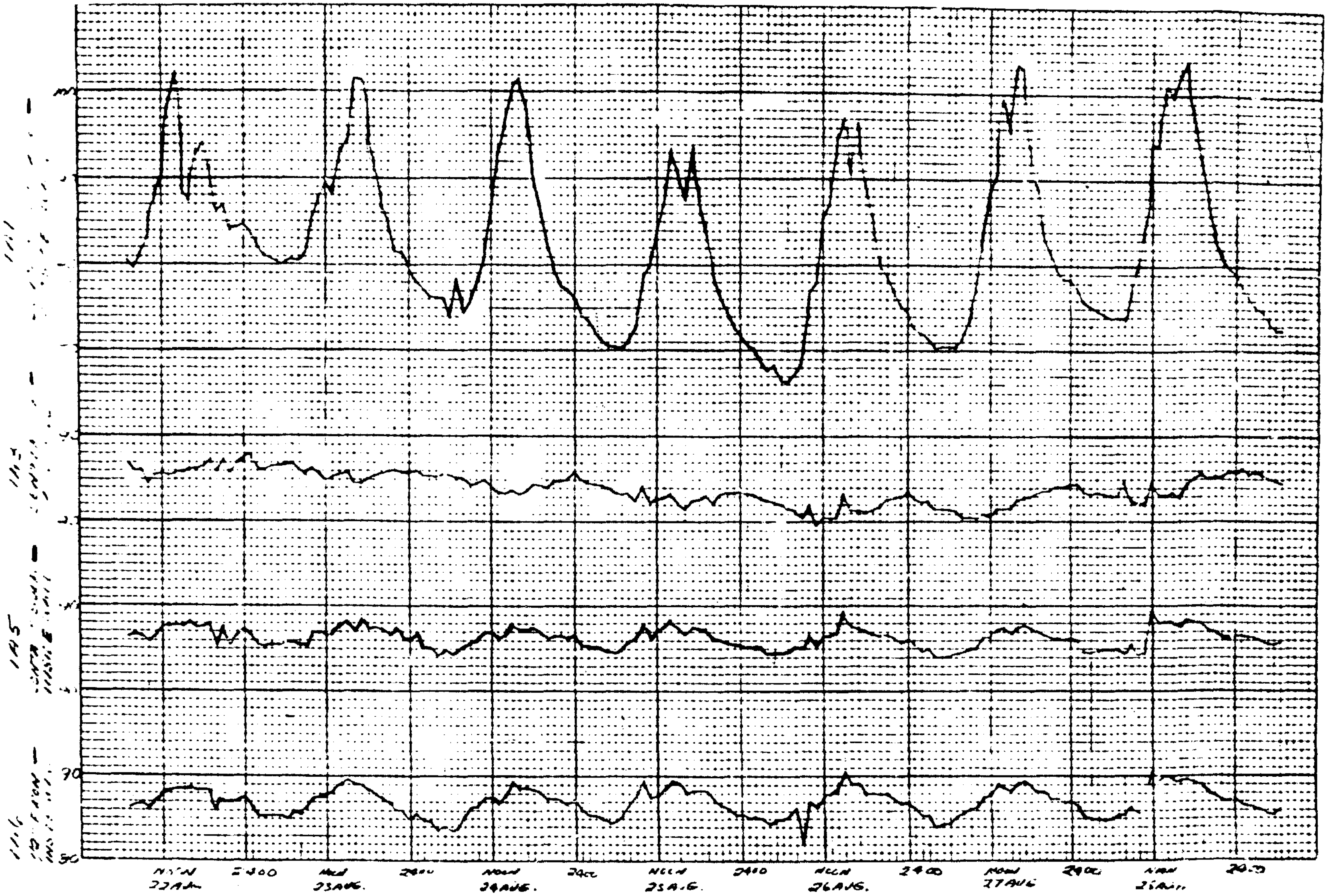


Figure 5.6 (cont'd). Wall temperatures, southeast wall.

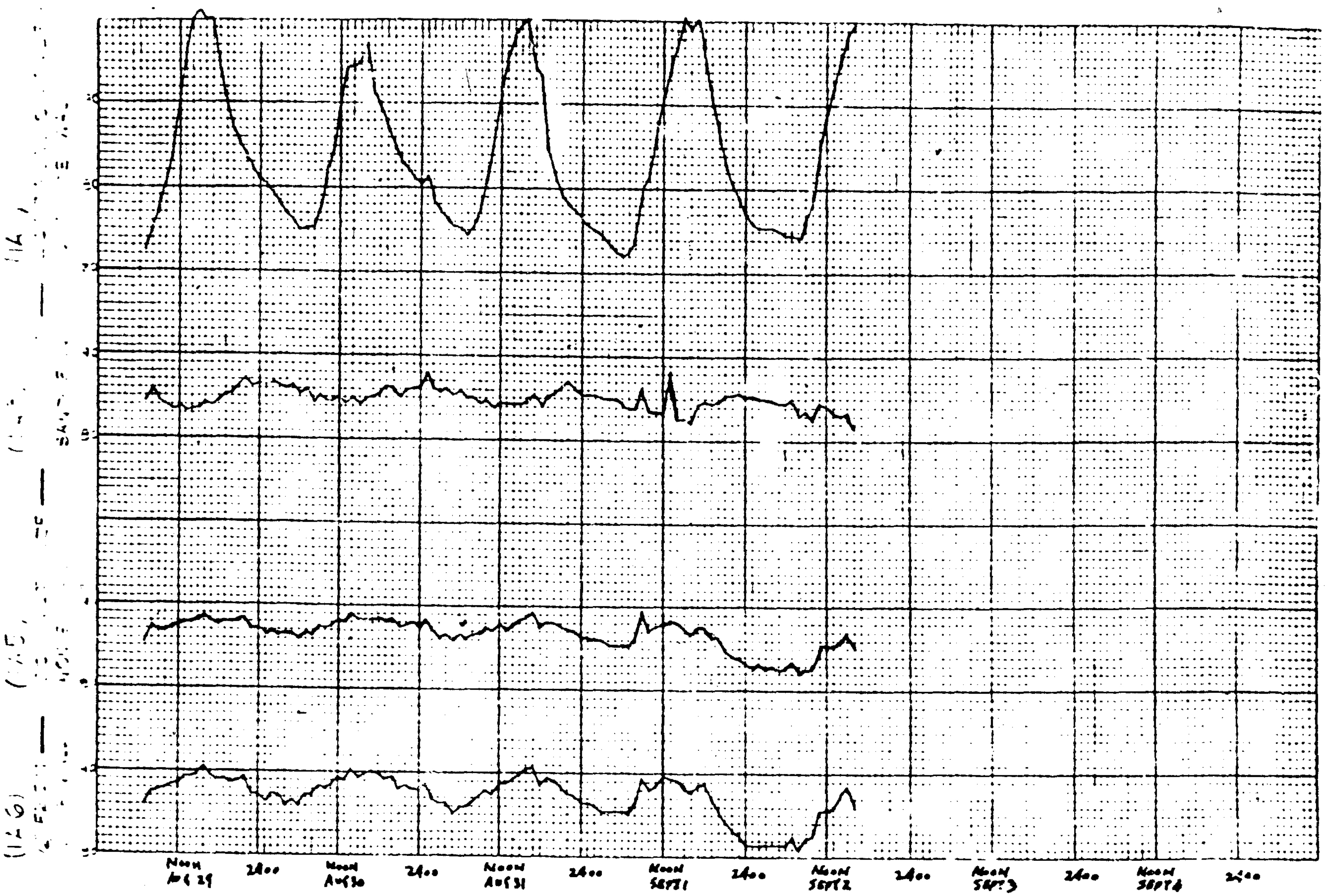


Figure 3.6 (cont'd). Wall temperatures, southeast wall.

Figure 3.7 Wall temperatures, geometric center, east wall.

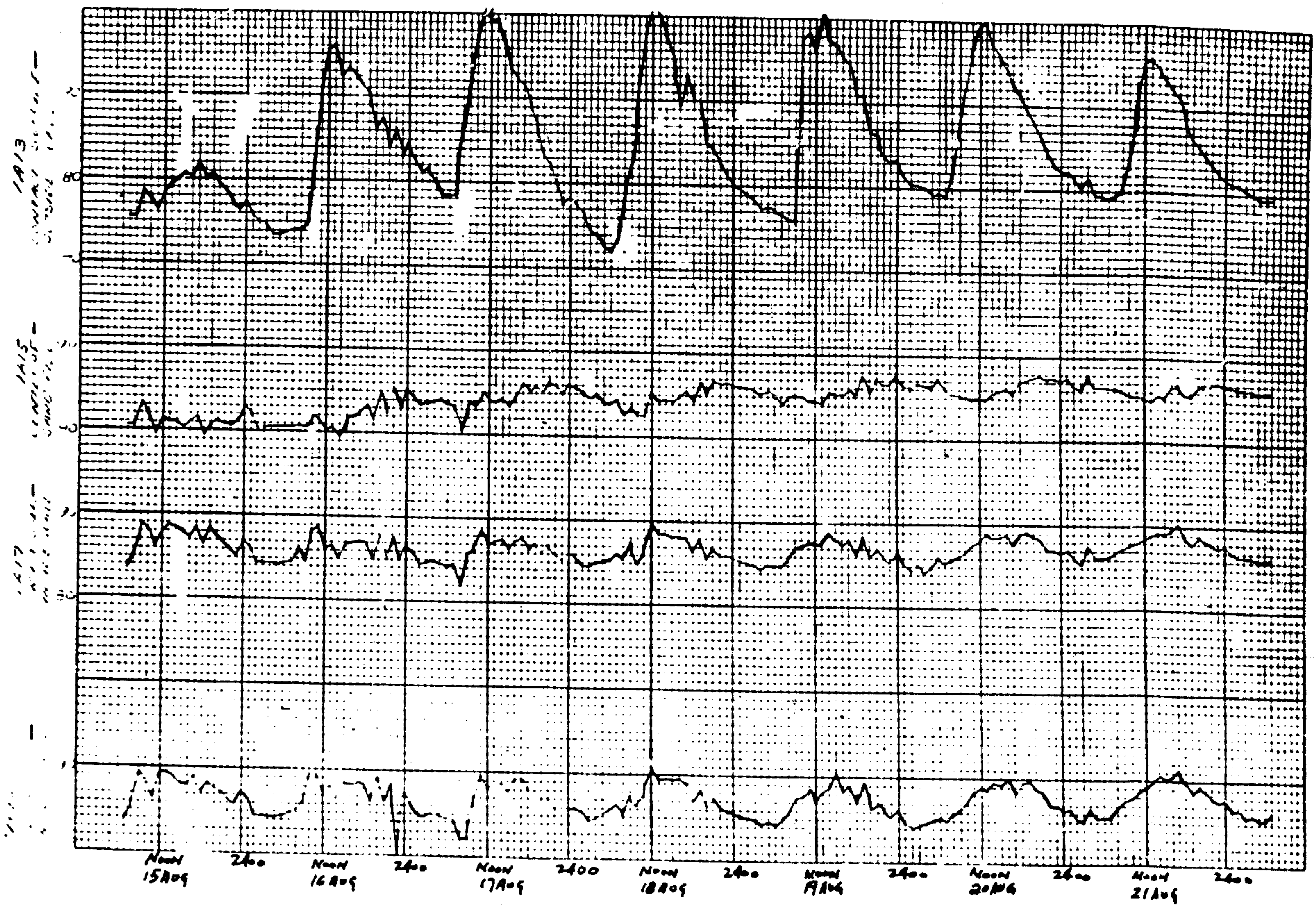


Figure 3.7 (cont'd). Wall temperatures, geometric center, east wall.

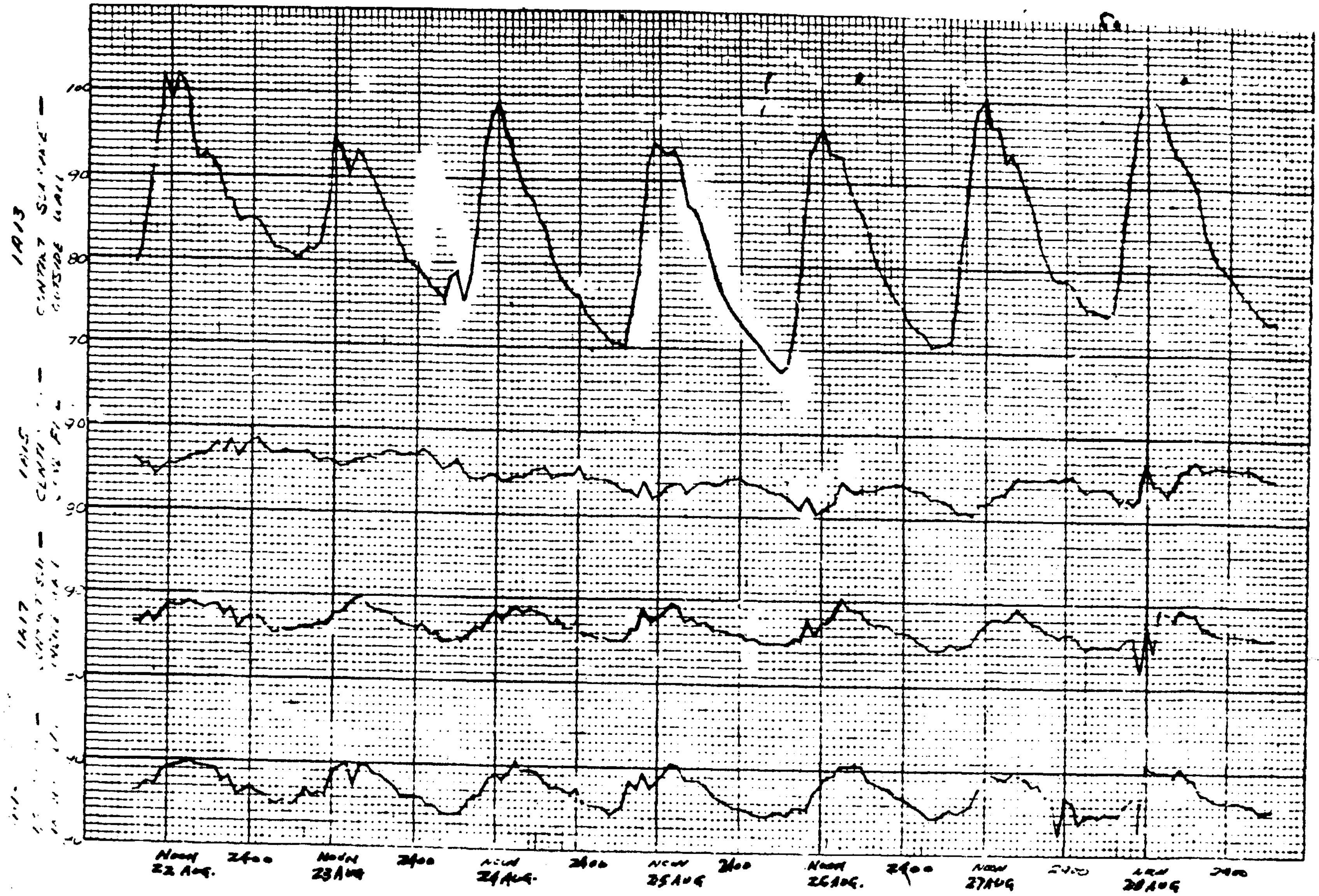


Figure 3.7 (cont'd). Wall temperatures, geometric center, east wall.

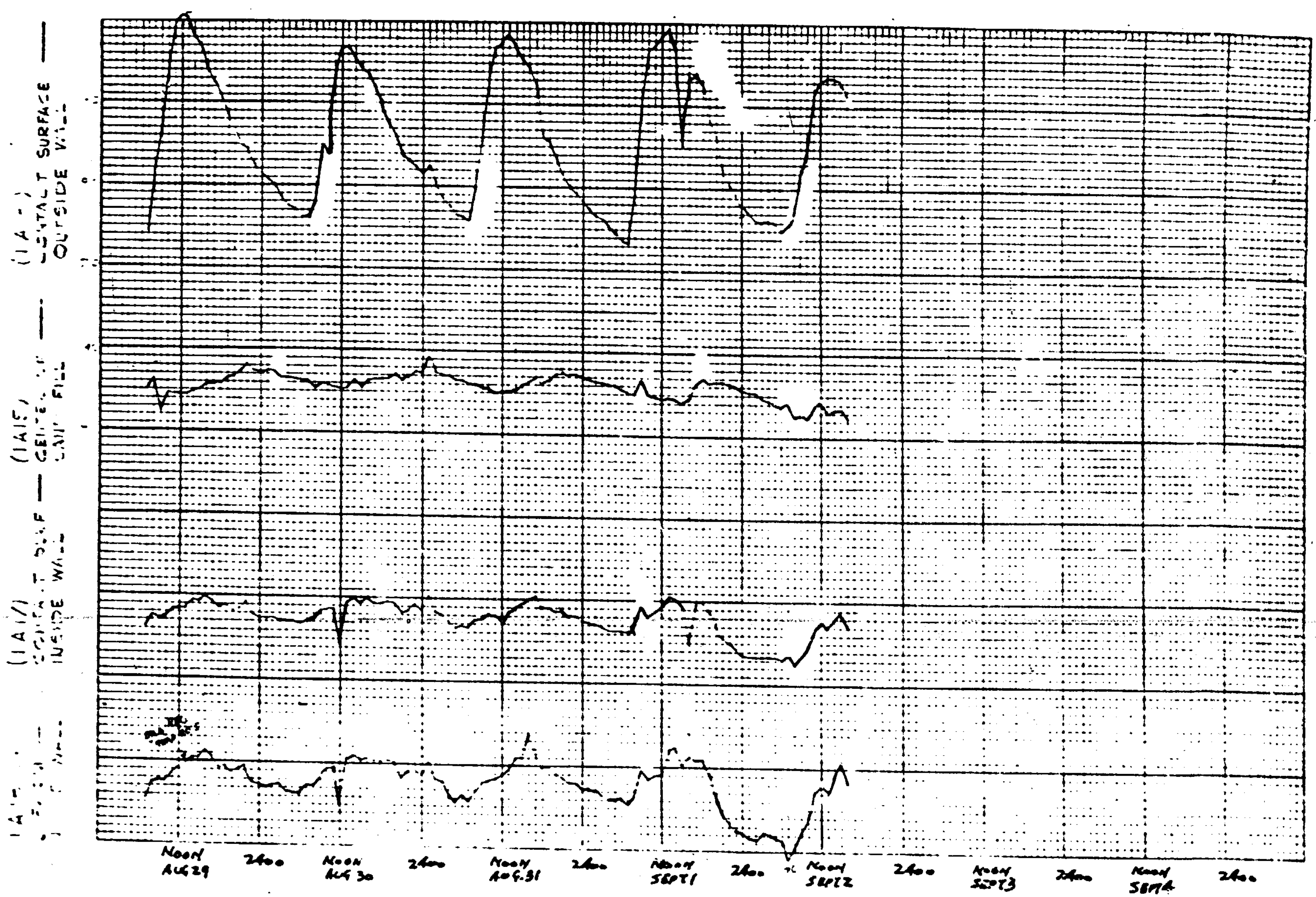


Figure 3.7 (cont'd). Wall temperatures, geometric center, east wall.

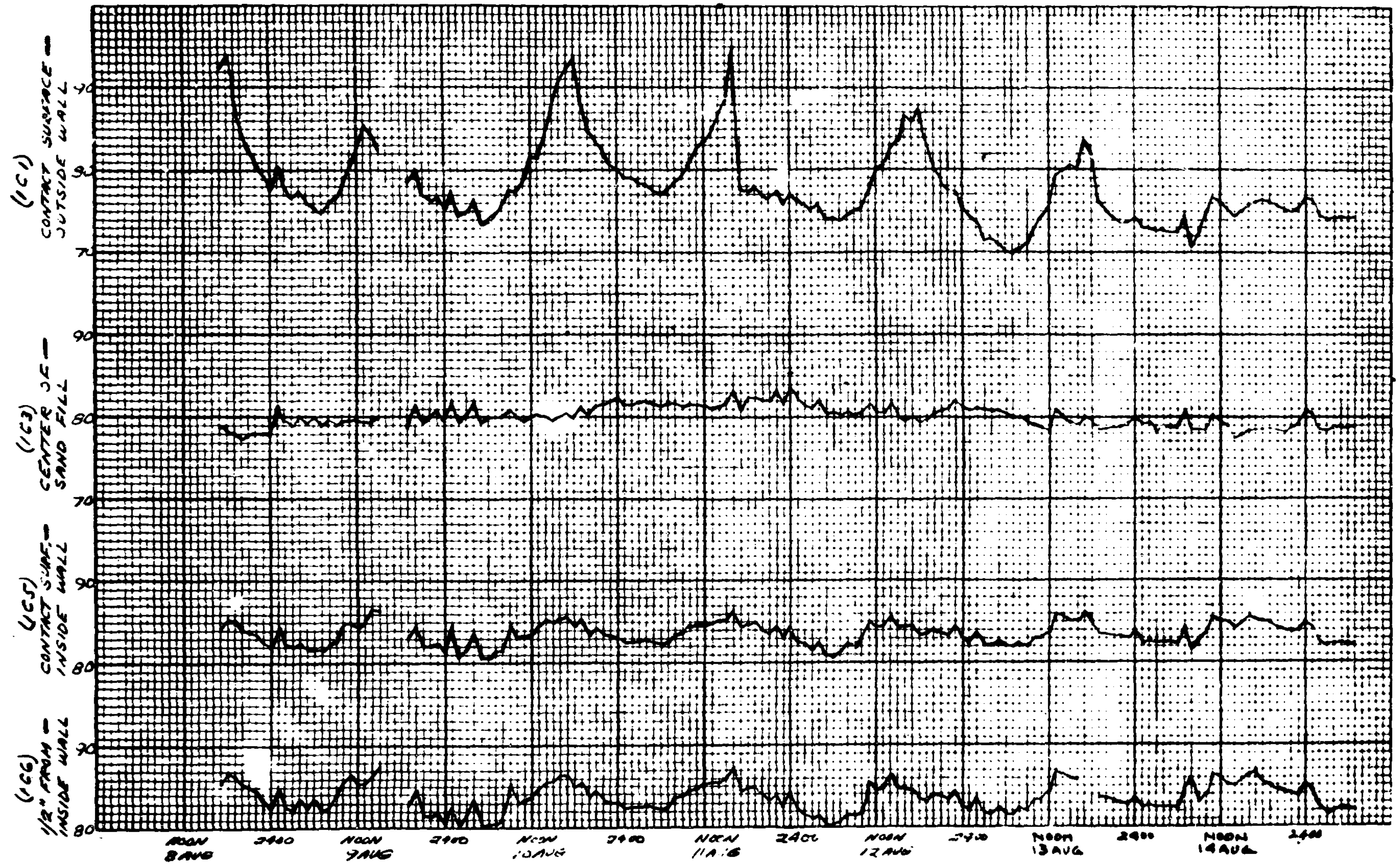


Figure 3.8 Wall temperatures, geometric center, west wall.

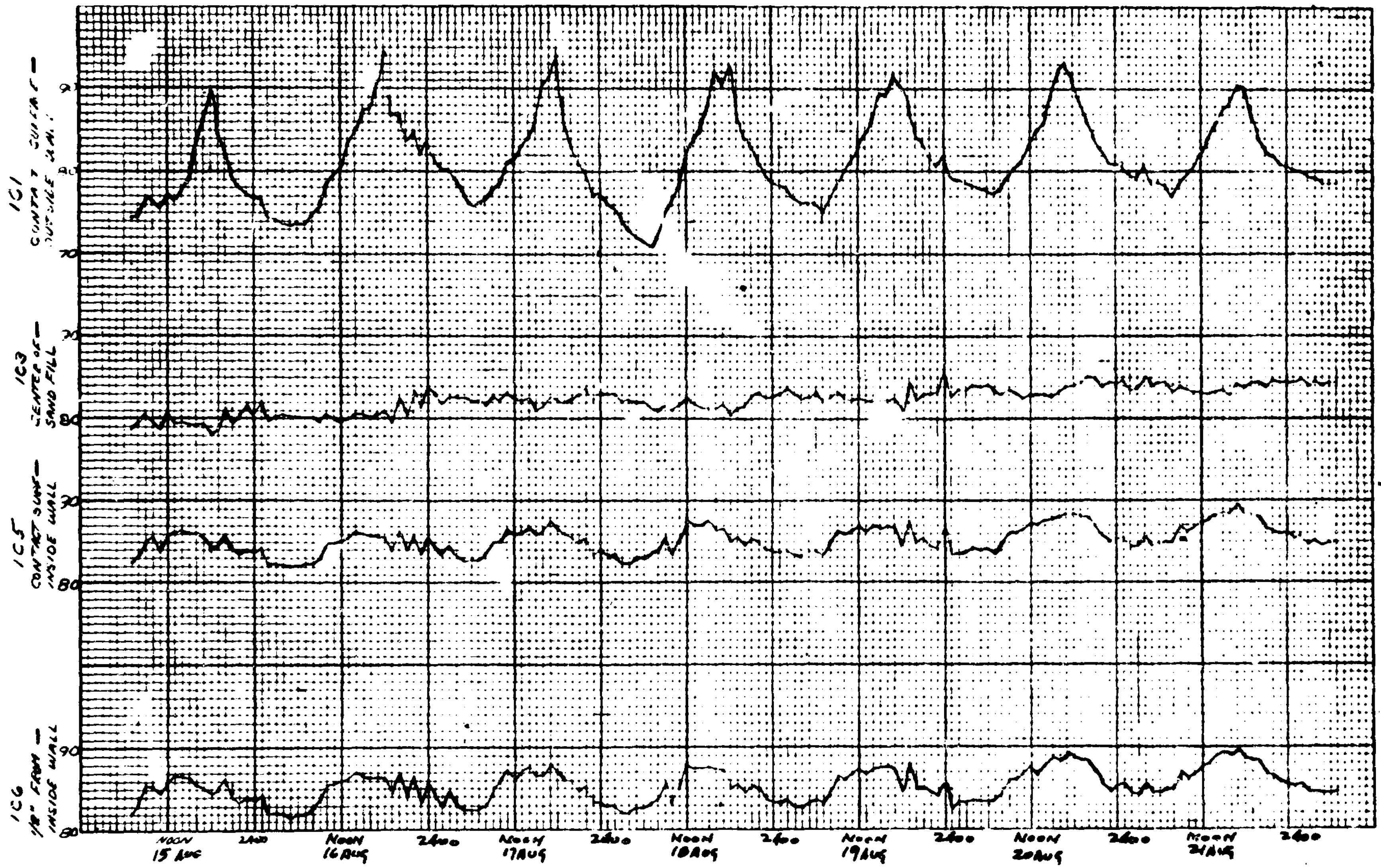


Figure 3.8 (cont'd). Wall temperatures, geometric center, west wall.

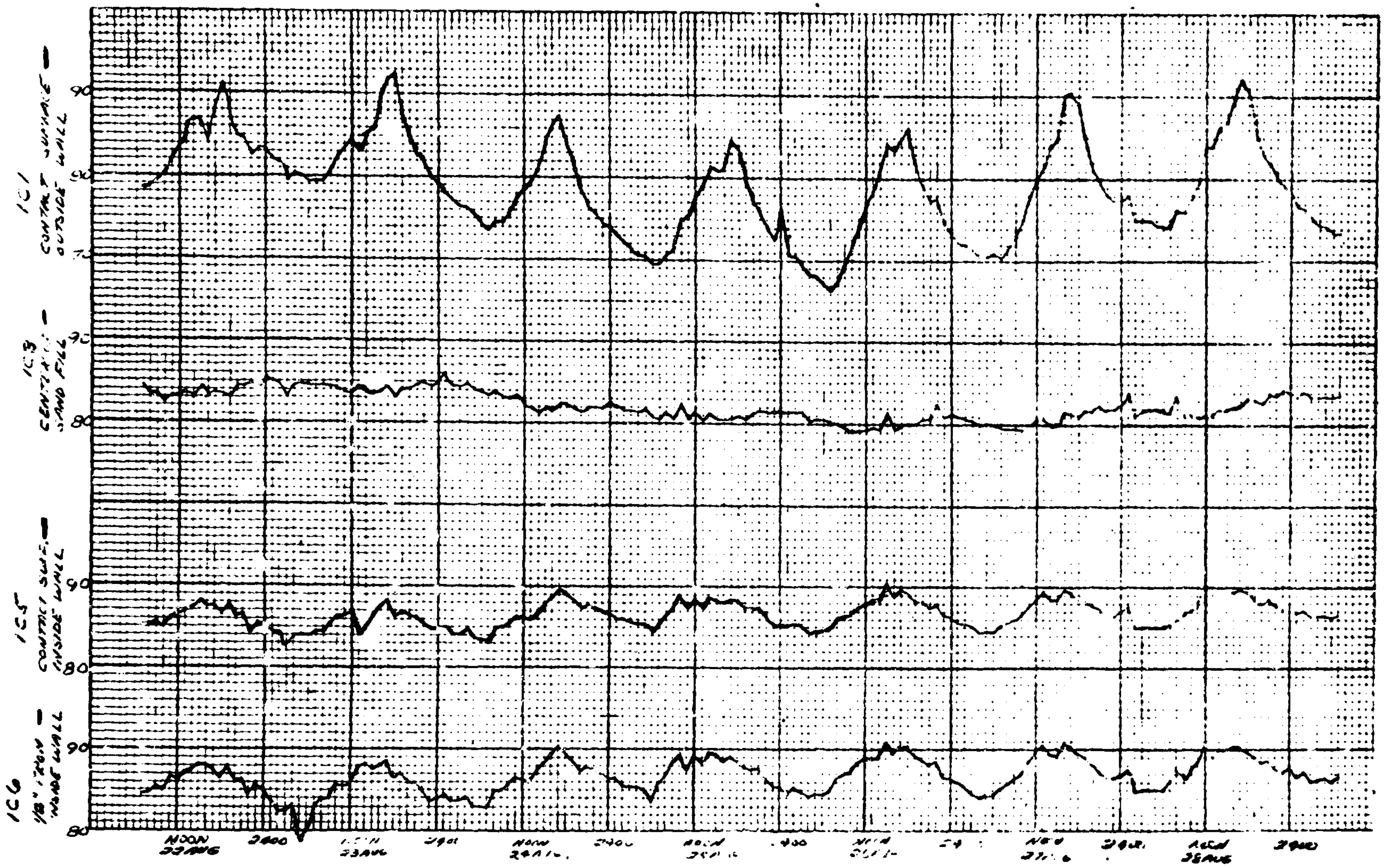


Figure 3.8 (cont'd). Wall temperatures, geometric center, west wall.

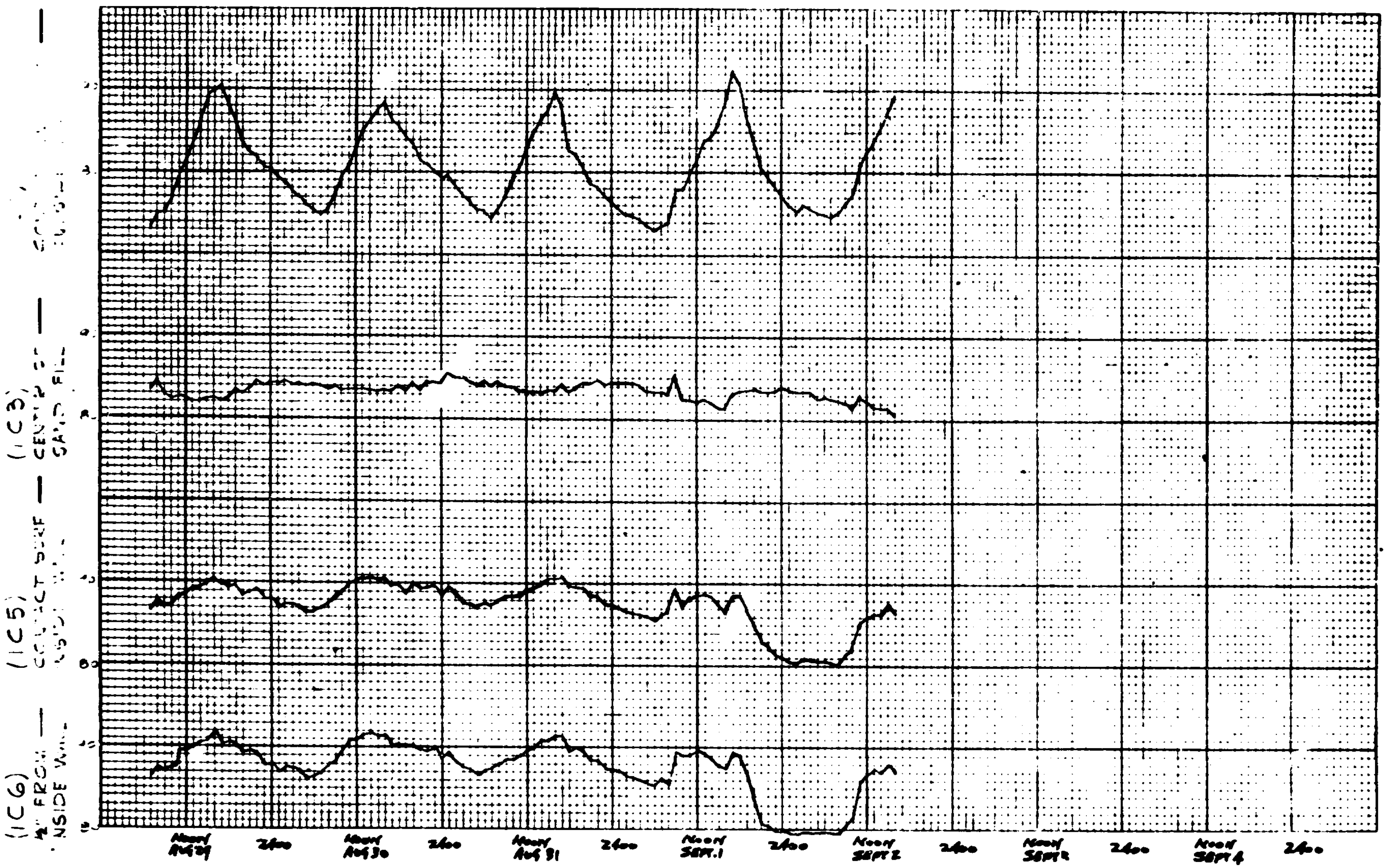


Figure 3.8 (cont'd). Wall temperatures, geometric center, west wall.

CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS

4.1 SHELTER THERMAL RESPONSE

4.1.1 Optimum Ventilation Rate. Based on the criteria of a maximum allowable effective temperature of 82 degrees for the 10% Washington, D. C. design day and a loading rate of 10 square feet per person, the optimum ventilation rate for the shelter was found to be 15 cfm per person. This is in agreement with the rate established by Drucker's generalized computer program for analysis of the thermal environment in protective structures.

4.1.2 Shelter Thermal Conditions at Overcrowding. With ventilation provided at 15 cfm per person, the ambient air at the 10% Washington, D. C. design day conditions, and a maximum allowable effective temperature of 82 degrees, the shelter would not be habitable when 33% overcrowded. The key element in this conclusion is the assumption that 82 degrees provides a cut-off between tolerable and intolerable conditions. This criterion may vary with an individual's response to conditions of thermal stress and his state of health. However, it is the current criteria, in use by the Office of Civil Defense and the U. S. Army Corps of Engineers, for establishing requirements for ventilation improvement in civilian fallout shelter facilities.

4.1.3 Air Distribution. Proper ventilation, of a shelter space, includes both the provision of a sufficient quantity of air and its efficient distribution. This shelter had adequate air supply to maintain

an acceptable thermal environment, but it also had relatively large "dead" areas in which there was little air movement. The use of punkahs, in lieu of duct work, to provide a more equitable distribution of the available air supply, was found to be effective.

4.2 RECOMMENDATIONS

a. That the ventilation rate for shelters, of this type, in Washington, D. C. and areas of similar climate be established at a minimum rate of 15 cfm per occupant.

b. That provisions be made in developing shelter programs to avoid overcrowding (less than 10 sq ft per person) in shelters of this type in the Washington, D. C. and areas of similar climate.

c. That auxiliary air moving devices, punkahs in particular, be considered for inclusion as an item of Office of Civil Defense materiel.

d. That additional comparisons be made between experimentally and analytically determined ventilation rates for protective structures to establish the reliability and range of applicability of the latter.

APPENDIX A

10% DESIGN DAY - FORT BELVOIR, VIRGINIA

1. Weather data obtained from Davison US Army Air Field, Ft. Belvoir, Va., and the design data temperatures given in "Army, Navy and Air Force Manual, Engineering Weather Data," TM 5-785, Departments of the Army, Navy, and Air Force, April 1963, were used to determine the 10% design day. The dry bulb and wet bulb temperatures obtained from Davison were adjusted by increasing all temperatures an amount equal to the difference between the maximum temperatures given in the two references. Two adjusted curves were thus obtained; one for dry bulb and one for wet bulb.

Davison US Army Field Data*

July	DB°F	WB°F
0000 - 0200	69.5	66.9
0300 - 0500	67.2	65.3
0600 - 0800	71.1	67.5
0900 - 1100	80.1	71.3
1200 - 1400	84.3	72.3
1500 - 1700	84.1	72.3
1800 - 2000	79.0	71.3
2100 - 2300	72.7	68.9

* Five year average - Feb 57 - Apr 62.

TM 5-785 Data

Max DB = 87°F
Max WB = 75°F

2. The hourly coincident DB and WB temperatures from these curves were then tabulated and the average Dew Point temperature over the 24-hour period determined. Then with the constant average Dew Point (DP) and the high 10% design day DB temperatures, a new set of corresponding WB temperatures were determined.

Table A.1
10% Design Day Temperatures

TIME	DB	WB	DP	AVERAGE DP	NEW WB
2400	72.8	69.9	68.6		70.3
0100	71.9	69.2	68.0		70.1
0200	70.9	68.6	67.4		69.8
0300	70.0	68.1	67.0		69.5
0400	69.8	67.9	67.1		69.5
0500	70.0	68.0	67.0		69.5
0600	71.0	68.8	67.8		69.8
0700	73.3	69.9	68.4		70.5
0800	76.9	71.4	69.2		71.6
0900	79.7	72.7	69.7		72.3
1000	82.1	73.8	70.2		73.0
1100	83.9	74.2	70.2	69.3	73.5
1200	85.1	74.7	70.4		74.0
1300	86.2	74.9	70.5		74.2
1400	86.9	75.0	70.3		74.3
1500	86.9	75.0	70.3		74.3
1600	86.4	74.9	70.3		74.2
1700	85.3	74.7	70.3		74.0
1800	83.6	74.2	70.2		73.5
1900	81.3	73.8	70.4		72.9
2000	79.0	73.0	70.3		72.1
2100	76.9	72.2	70.2		71.5
2200	75.0	71.3	70.0		71.0
2300	73.6	70.[illegible]	69.2		70.6

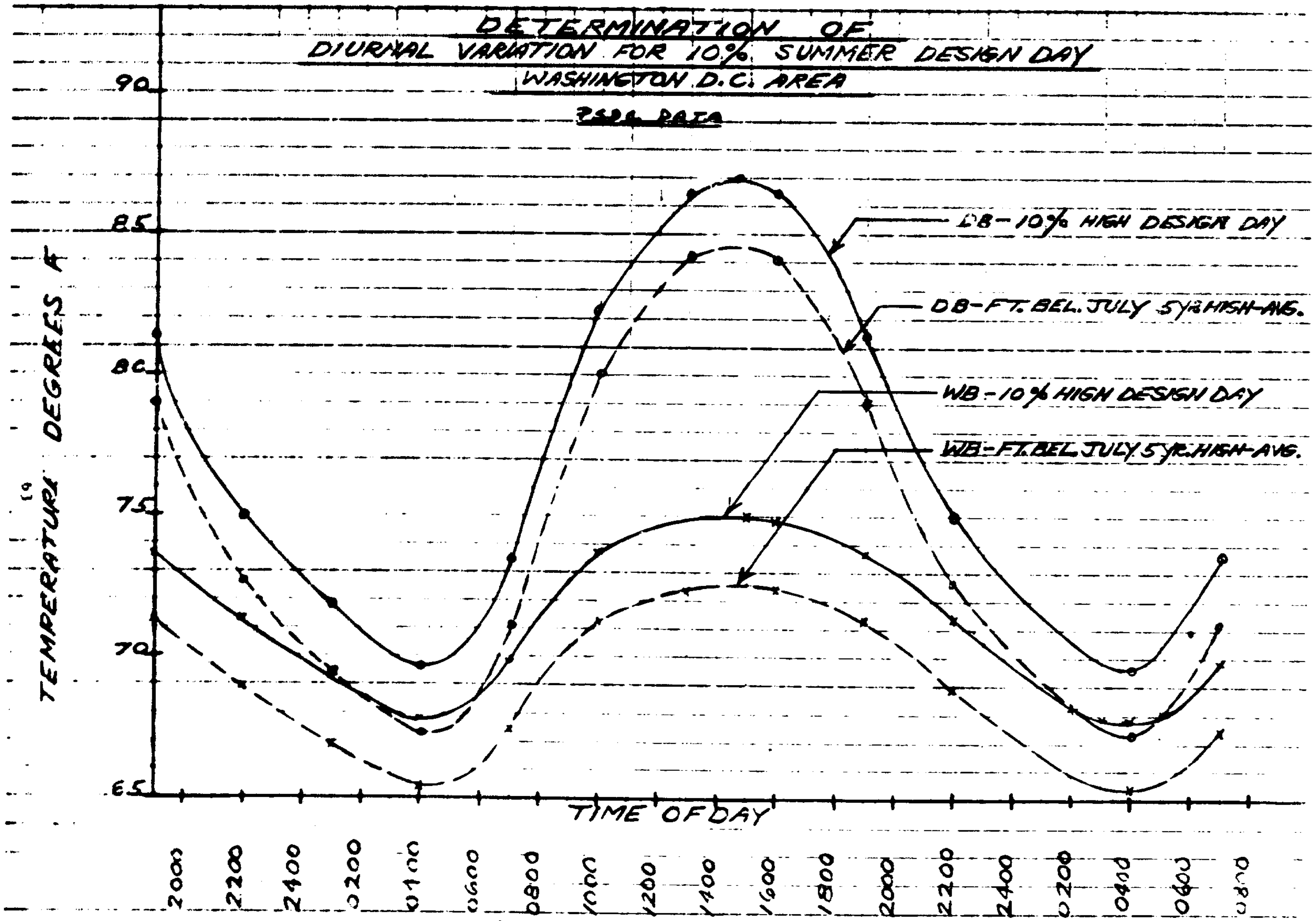


Figure A.1 Basic temperature data.

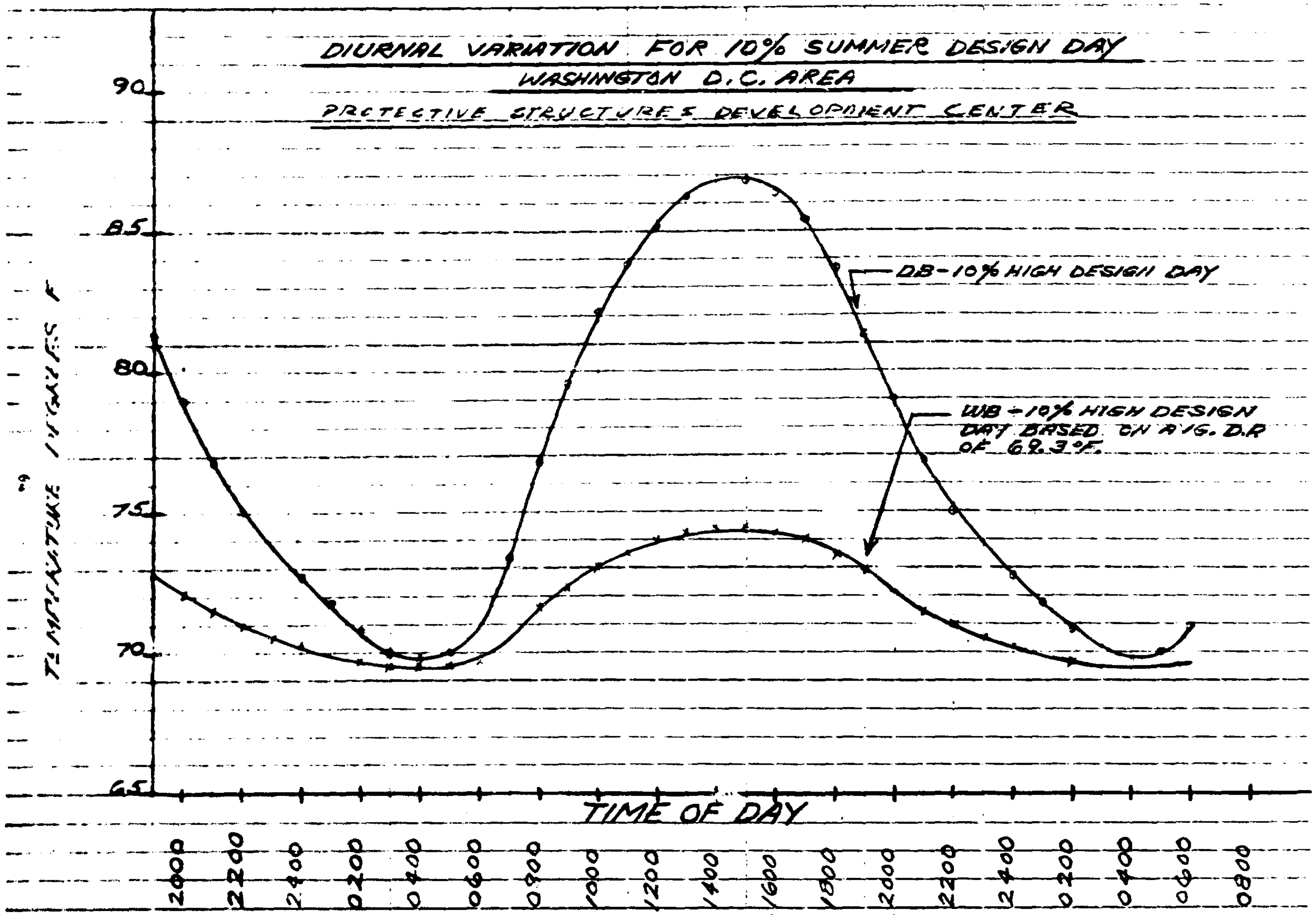


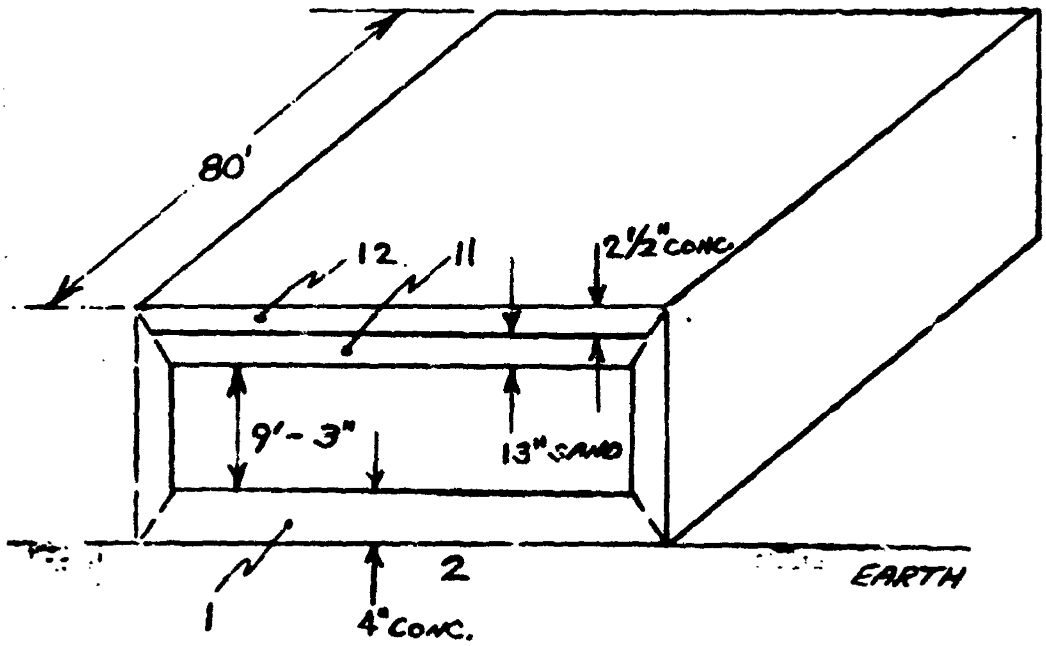
Figure A.2 10% Design Day, diurnal temperatures.

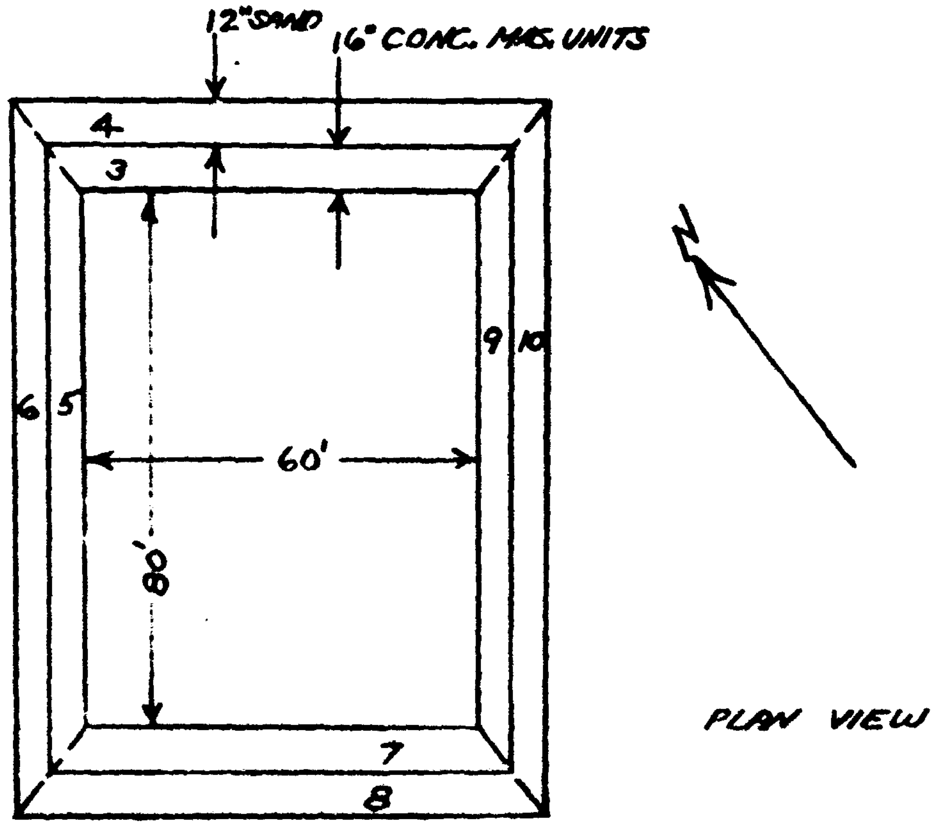
THERMAL ANALYSIS - 480 PERSON COMMUNITY SHELTER

NUMBER OF OCCUPANTS	PERS = 480.0
GEOGRAPHIC ZONE	JZONE = 3
DURATION OF OCCUPANCY	DAY1 = 1.0
DURATION OF OCCUPANCY	DAY2 = 3.0
DURATION OF OCCUPANCY	DAY3 = 7.0
DURATION OF OCCUPANCY	DAY4 = 10.0
DURATION OF OCCUPANCY	DAYTO = 14.0
HEAT RELEASE	QH = 4.1
MOISTURE RELEASE	WADD = 0.0000
VENTILATION RATE LIMIT	QVLT = 18.0
EARTH TEMPERATURE	TE = 75.0
OUTSIDE DRY BULB TEMPERATURE	
MAXIMUM	TOMAX = 87.0
AMPLITUDE	TAMPL = 9.0
OUTSIDE HUMIDITY RATIO	WO = 0.0160
LENGTH PARTIAL PERIOD	JHOUR = 6

WALL NUMBER	THICKNESS (INCHES)	WIDTH (FT)	BREADTH (FT)	DENSITY	CONDUCTIVITY	SPECIFIC HEAT	L1	L3	L4	L6
1	4.00	60.00	80.00	144.00	1.00	0.22	1	1	3	0
2	60.00	60.00	80.00	92.00	1.08	0.20	1	1	2	0
3	16.00	9.25	60.00	116.00	0.62	0.22	1	1	3	1
4	12.00	10.88	64.67	110.00	0.63	0.20	1	1	1	1
5	16.00	9.25	20.00	116.00	0.62	0.22	1	1	3	4
6	12.00	10.38	84.67	110.00	0.63	0.20	1	1	1	4
7	16.00	9.25	60.00	116.00	0.62	0.22	1	1	3	3
8	12.00	10.88	67.67	110.00	0.63	0.20	1	1	1	3
9	16.00	9.25	80.00	116.00	0.62	0.22	1	1	3	2
10	12.00	10.88	84.67	110.00	0.63	0.20	1	1	1	2
11	13.00	60.00	80.00	110.00	0.63	0.20	1	1	3	0
12	2.50	64.67	84.67	144.00	1.00	0.22	1	1	1	0

APPENDIX B





DIMENSIONS - 480 PERSON COMMUNITY SHELTER

APPENDIX B

Table B.1

Material Properties - 480 Person Community Shelter

Material	Cp	K	Density
CMU walls	0.22	0.615	116 lb/ft^2
Sand in walls	0.20	0.63	110 lb/ft^2
Sand in roof	0.20	0.63	110 lb/ft^2
Concrete	0.22	1.00	144 lb/ft^2
Earth	0.20	1.08	98 lb/ft^2

$K = \frac{BTU\text{-}Ft}{Hr\text{-}Ft^2\text{-}F^o}$ (thermal conductivity)

$Cp = \frac{BTU}{lb/F^o}$ (specific heat)

480 PERSON AUSTERE SHELTER P S D C FT BELVOIR VA

NUMBER OF OCCUPANTS	PERS=******
GEOGRAPHIC ZONE	JZONE= 3
DURATION OF OCCUPANCY	DAY1= 1.0
DURATION OF OCCUPANCY	DAY2= 3.0
DURATION OF OCCUPANCY	DAY3= 7.0
DURATION OF OCCUPANCY	DAY4=10.0
DURATION OF OCCUPANCY	DAYTO=14.0
HEAT RELEASE	QH= 4.1
MOISTURE RELEASE	WADD=0.000
VENTILATION RATE LIMIT	QVLT=18.0
AIR COOLING LIMIT	QACLM=0.000
SENSIBLE HEAT FACTOR	SHFA=0.00
EARTH TEMPERATURE	TE=75.0
OUTSIDE DRY BULB TEMPERATURE	
MAXIMUM	TOMAX= 87.0
AMPLITUDE	TAMPL= 9.0
OUTSIDE HUMIDITY RATIO	WO=0.0160
LENGTH PARTIAL PERIOD	JHOUR= 6

WALL NUMBER	THICKNESS (INCHES)	WIDTH (FT)	BREADTH (FT)	DENSITY	CONDUCT-IVITY	SPECIFIC HEAT	L1	L3	L4	L6
1	4.00	60.00	80.00	144.00	1.00	0.22	1	1	[illegible]	0
2	60.00	60.00	80.00	92.00	1.08	0.20	1	1	[illegible]	0
3	16.00	9.25	60.00	51.50	0.62	0.22	2	1	[illegible]	1
4	12.00	10.88	62.16	110.00	0.63	0.20	2	1	[illegible]	1
5	16.00	9.25	80.00	51.50	0.62	0.22	2	1	[illegible]	4
6	12.00	10.88	82.16	110.00	0.63	0.20	2	1	[illegible]	4
7	16.00	9.25	60.00	51.50	0.62	0.22	2	1	[illegible]	3
8	12.00	10.88	62.16	110.00	0.63	0.20	2	1	[illegible]	3
9	16.00	9.25	80.00	51.50	0.62	0.22	2	1	[illegible]	2
10	12.00	10.88	82.16	110.00	0.63	0.20	2	1	[illegible]	2
11	13.00	60.00	80.00	129.00	0.63	0.20	1	1	[illegible]	0
12	2.50	62.16	82.16	144.00	1.00	0.22	1	1	[illegible]	0

APPENDIX B

TIME (HRS)	VENT RATE (CFM/P)	COOL RATE (TONS/P)	MAX ET (24HR)	AVG ET (24HR)	AVG ET (J-HR)	MAX DB TEMP	MAX HUMIDITY (24HR)
24.0	3.00	0.000	98.72	97.04	98.57	97.04	0.039.63
72.0	3.00	0.000	98.82	97.26	98.67	99.58	41.01
168.0	3.00	0.000	98.83	97.28	98.68	99.58	41.03
240.0	3.00	0.000	98.83	97.28	98.68	99.58	41.03
336.0	3.00	0.000	98.83	97.28	98.68	99.58	41.03
24.0	6.00	0.000	90.71	88.51	90.51	92.66	26.76
72.0	6.00	0.000	90.75	88.58	90.54	96.61	27.84
168.0	6.00	0.000	90.75	88.59	90.55	96.63	27.85
240.0	6.00	0.000	90.75	88.59	90.55	96.63	27.85
336.0	6.00	0.000	90.75	88.59	90.55	96.63	27.85
24.0	9.00	0.000	87.82	85.19	87.58	89.98	22.67
72.0	9.00	0.000	87.85	85.24	87.60	94.85	23.58
168.0	9.00	0.000	87.86	85.25	87.61	94.86	23.59
240.0	9.00	0.000	87.86	85.25	87.61	94.86	23.59
336.0	9.00	0.000	87.86	85.25	87.61	94.86	23.59
24.0	12.00	0.000	86.27	83.31	85.99	88.14	20.75
72.0	12.00	0.000	86.29	83.34	86.01	93.64	21.52
168.0	12.00	0.000	86.29	83.35	86.02	93.64	21.52
240.0	12.00	0.000	86.29	83.35	86.02	93.65	21.52
336.0	12.00	0.000	86.29	83.35	86.02	93.65	21.52
24.0	15.00	0.000	85.27	82.06	84.98	86.80	19.65
72.0	15.00	0.000	85.29	82.08	84.99	92.75	20.32
168.0	15.00	0.000	85.29	82.09	85.00	92.76	20.32
240.0	15.00	0.000	85.29	82.09	85.00	92.76	20.32
336.0	15.00	0.000	85.29	82.09	85.00	92.76	20.32
24.0	18.00	0.000	84.58	81.15	84.26	85.76	18.94
72.0	18.00	0.000	84.59	81.18	84.28	92.07	19.53
168.0	18.00	0.000	84.60	81.18	84.28	92.08	19.53
240.0	18.00	0.000	84.60	81.18	84.28	92.08	19.53
336.0	18.00	0.000	84.60	81.18	84.28	92.08	19.53

APPENDIX C

Table C.1

Thermocouple Location Data

Pot. No. Section, Print No.	Probe Position	Thermo-couple No.	Location
1-A-1	A	1	Contact, surface outside wall
2		2	Inner surface of outside block layer
3		3	Center of sand fill
4		4	Inner surface of inside block layer
5		5	Contact, surface inside wall
6		6	1/2" in air
7	B	7	Contact, surface outside wall
8		8	Inner surface of outside block layer
9		9	Center of sand fill
10		10	Inner surface of inside block layer
11		11	Contact, surface inside wall
12		12	1/2" in air
13	C	13	Contact, surface outside wall
14		14	Inner surface of outside block layer
15		15	Center of sand fill
16		16	Inner surface of inside block layer
17		17	Contact, surface inside wall
18		18	1/2" in air
19	D	19	Contact, surface outside wall
20		20	Inner surface of outside block layer
21		21	Center of sand fill
22		22	Inner surface of inside block layer
23		23	Contact, surface inside wall
1-A-24		24	1/2" in air
1-B-1	E	25	Contact, surface outside wall
2		26	Inner surface of outside block layer
3		27	Center of sand fill
4		28	Inner surface of inside block layer
5		29	Contact, surface inside wall
6		30	1/2" in air
7	F	31	Contact, surface outside wall
8		32	Inner surface of outside block layer
9		33	Center of sand fill
10		34	Inner surface of inside block layer
11		35	Contact, surface inside wall
12		36	1/2" in air
13	G	37	Contact, surface outside wall
14		38	Inner surface of outside block layer
15		39	Center of sand fill
16		40	Inner surface of inside block layer
17		41	Contact, surface inside wall
18		42	1/2" in air
19	H	43	Contact, surface outside wall
20		44	Inner surface of outside block layer
21		45	Center of sand fill

APPENDIX C
Table C.1

Thermocouple Location Data (Cont'd)

Pot. No. Section, Print No.	Probe Position	Thermo-couple No.	Location
1-B-22		46	Inner surface of inside block layer
23		47	Contact, surface inside wall
1-B-24		48	1/2" in air
1-C- 1	I	49	Contact, surface outside wall
2		50	Inner surface of outside block layer
3		51	Center of sand fill
4		52	Inner surface of inside block layer
5		53	Contact, surface inside wall
6		54	1/2" in air
7	J	55	Contact, surface outside wall
8		56	Inner surface of outside block layer
9		57	Center of sand fill
10		58	Inner surface of inside block layer
11		59	Contact, surface inside wall
12		60	1/2" in air
13	K	61	Contact, surface outside wall
14		62	Inner surface of outside block layer
15		63	Center of sand fill
16		64	Inner surface of inside block layer
17		65	Contact, surface inside wall
18		66	1/2" in air
19	I	67	Contact, bottom roof slab
20		68	Center of sand fill
21		69	1" in sand above steel deck
22		70	Contact, steel deck
23		71	Vertical probe, 6' off floor
1-C-24		72	Vertical probe, 4' off floor
1-D- 1		73	Vertical probe, 2' off floor
2		74	Contact, concrete floor surface
3		75	Bottom of floor slab
4		76	6" in soil, below floor slab
5		77	12" in soil, below floor slab
6		78	24" in soil, below floor slab
7	II	79	Contact, bottom roof slab
8		80	Center of sand fill
9		81	1" in sand above steel deck
10		82	Contact, steel deck
11		83	Vertical probe, 6' off floor
12		84	Vertical probe, 4' off floor
13		85	Vertical probe, 2' off floor
14		86	Contact, concrete floor surface
15		87	Bottom of floor slab
16		88	6" in soil, below floor slab
17		89	12" in soil, below floor slab
18		90	24" in soil, below floor slab
19	III	91	Contact, bottom roof slab
20		92	Center of sand fill

APPENDIX C

Table C.1

Thermocouple Location Data (Cont'd)

Pot. No. Section, Print No.	Probe Position	Thermo-couple No.	Location
1-D-21	III	93	1" in sand above steel deck
22		94	Contact, steel deck
23		95	Vertical probe, 6' off floor
1-D-24		96	Vertical probe, 4' off floor
2-E- 1		97	Vertical probe, 2' off floor
2		98	Contact, concrete floor surface
3		99	Bottom of floor slab
4		100	6" in soil, below floor slab
5		101	12" in soil, below floor slab
6		102	24" in soil, below floor slab
7	IV	103	Contact, bottom roof slab
8		104	Center of sand fill
9		105	1" in sand above steel deck
10		106	Contact, steel deck
11		107	Vertical probe, 6' off floor
12		108	Vertical probe, 4' off floor
13		109	Vertical probe, 2' off floor
14		110	Contact, concrete floor surface
15		111	Bottom of floor slab
2-E-16		112	6" in soil, below floor slab
2-F- 1		113	12" in soil, below floor slab
2		114	24" in soil, below floor slab
3	V	115	Contact, bottom roof slab
4		116	Center of sand fill
5		117	1" in sand above steel deck
6		118	Contact, steel deck
7		119	Vertical probe, 6' off floor
8		120	Vertical probe, 4' off floor
9		121	Vertical probe, 2' off floor
10		122	Contact, concrete floor surface
11		123	Bottom of floor slab
12		124	6" in soil, below floor slab
13		125	12" in soil, below floor slab
14		126	24" in soil, below floor slab
15		127	Referance
16		128	DB, Outside air, under trailer
3- 1	I	R-I	Roof surface, SE corner
2	II	R-II	Roof surface, NE corner
3	III	R-III	Roof surface, Geometric Center
4	IV	R-IV	Roof surface, NW corner
5	V	R-V	Roof surface, SW corner
Hygro-sensor Leads		[illegible]1	SE corner
		[illegible]2	East center, East-West center line
		[illegible]3	NE exhaust door
		[illegible]4	Geometric Center
		[illegible]5	NW exhaust door
		[illegible]6	NW corner

APPENDIX C
Table C.1

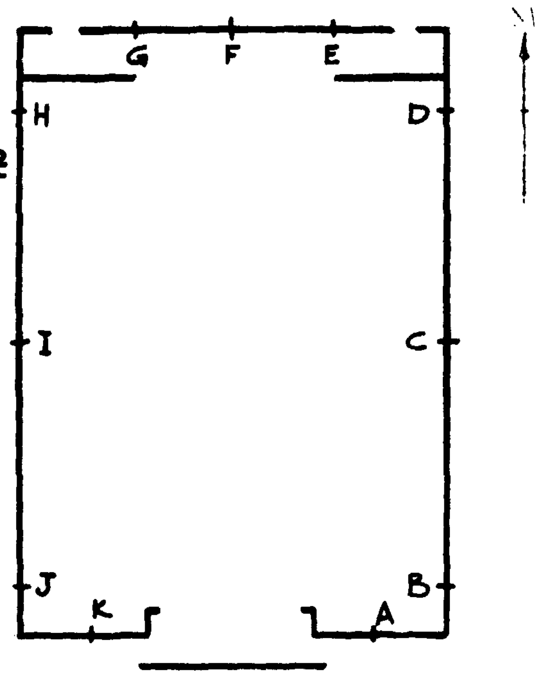
Thermocouple Location Data (Cont'd)

Pot. No. Section, Print No.	Probe Position	Thermo-couple No.	Location
Hygro-sensor heads		1	West center, East-West center line
		2	SW corner
		3	Supply air opening
		4	NE corner
		5	Outdoor air under trailer

WALL PROBES

11 POSITIONS "A" THRU "K"
WITH 6 THERMOCOUPLES
EACH (1 THROUGH 66)

POSITION	THERMOCOUPLE №
A	1-6
B	7-12
C	13-18
D	19-24
E	25-30
F	31-36
G	37-42
H	43-48
I	49-54
J	55-60
K	61-66



FLOOR, ROOF & VERTICAL PROBES

5 POSITIONS "I" THROUGH "V",
WITH 12 THERMOCOUPLES EACH

POSITION	THERMOCOUPLE №
I	67-78
II	79-90
III	91-102
IV	103-114
V	115-126

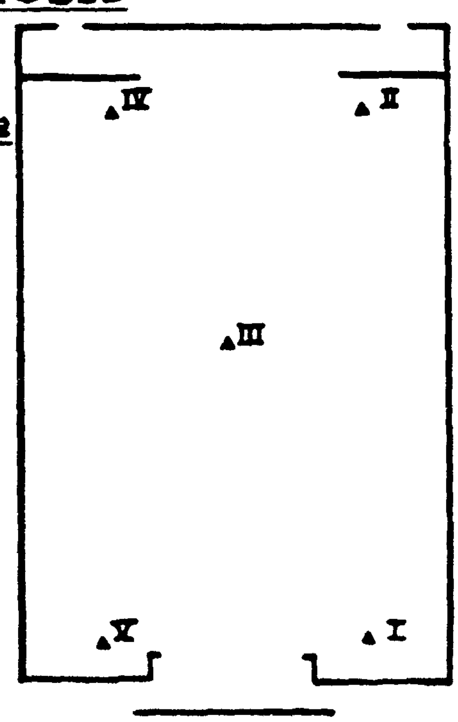


Figure C.1 Plan of thermocouple locations.

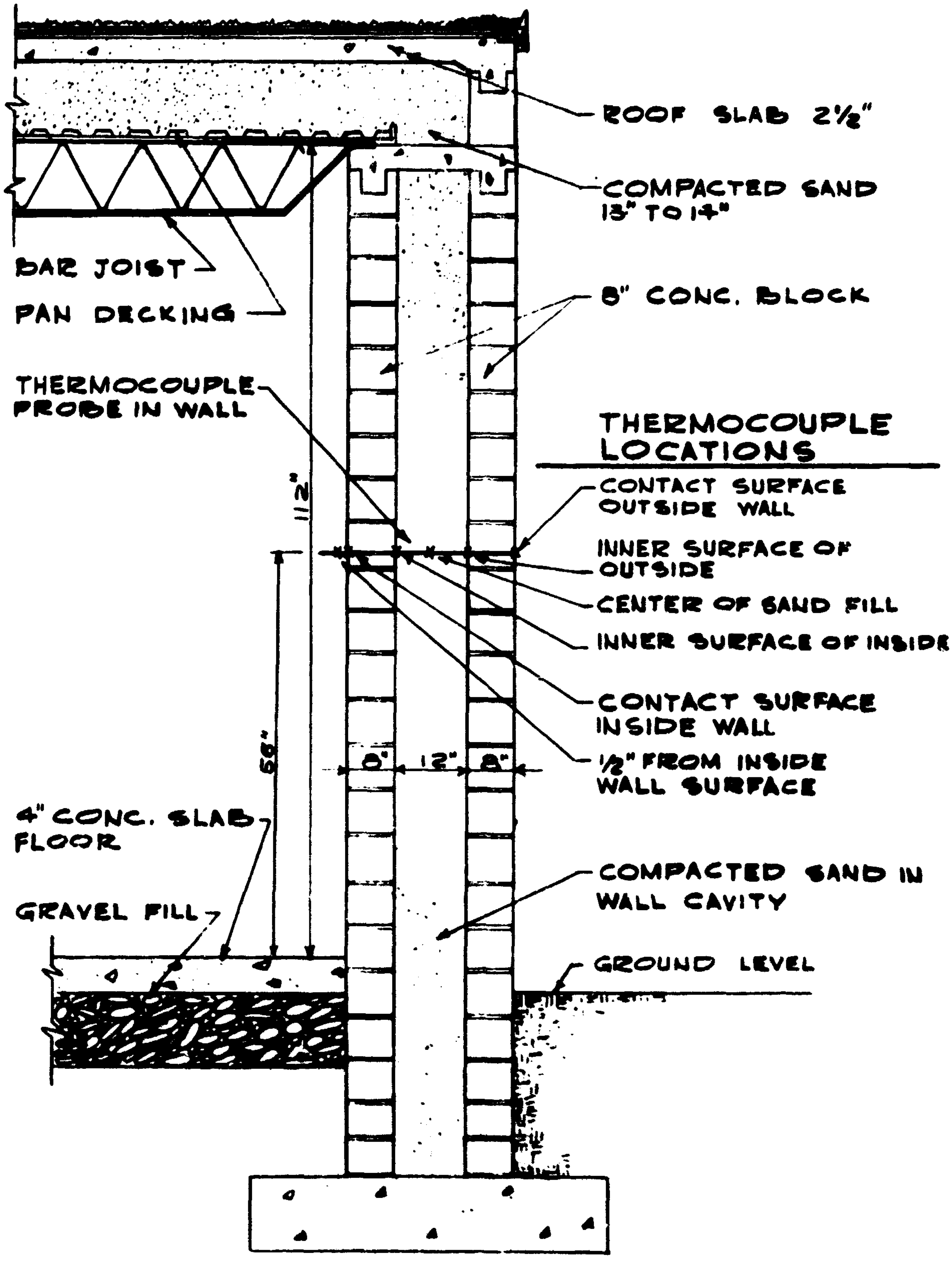


Figure C.2 Typical detail, thermocouple wall probes.

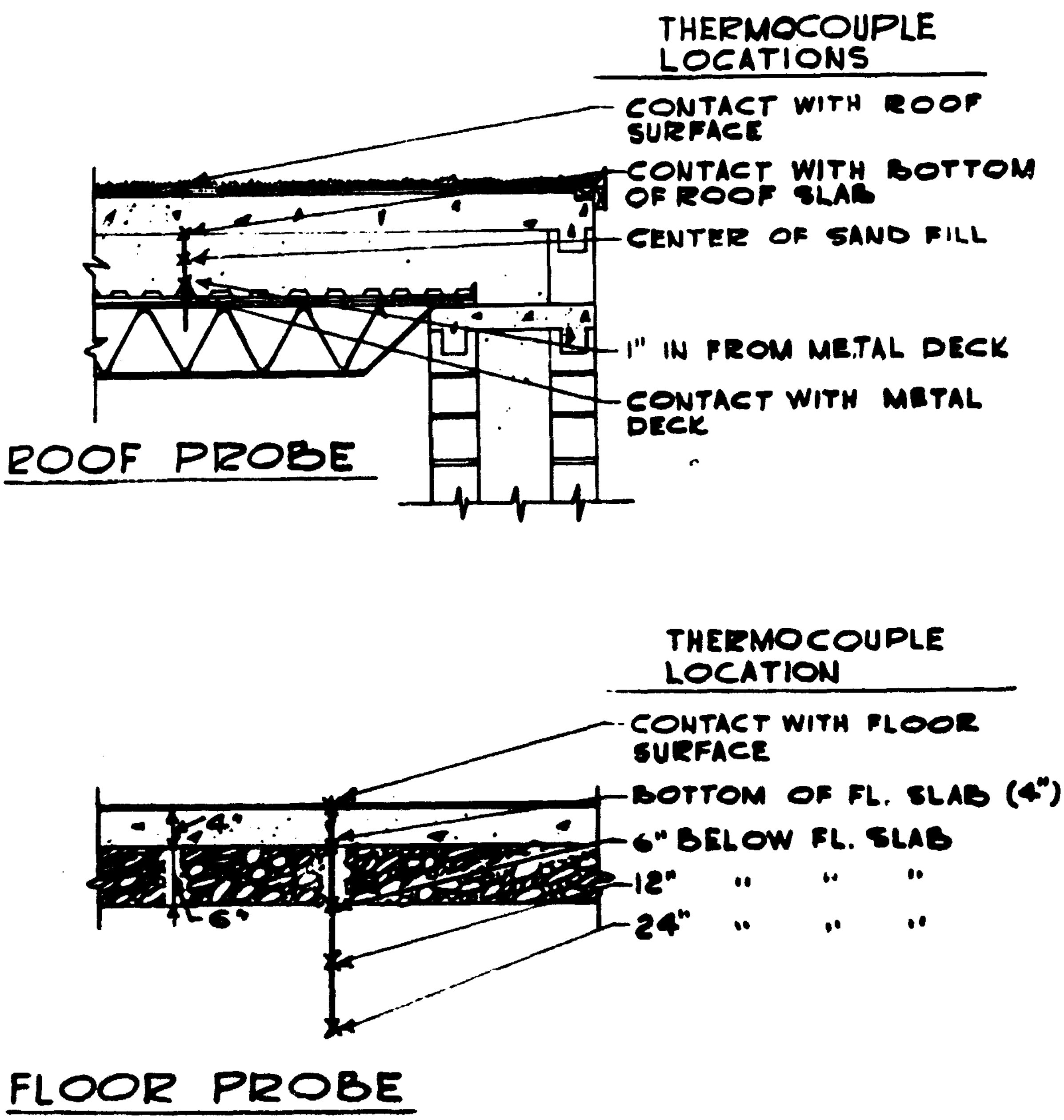


Figure C.3 Typical detail, thermocouple roof and floor probes.

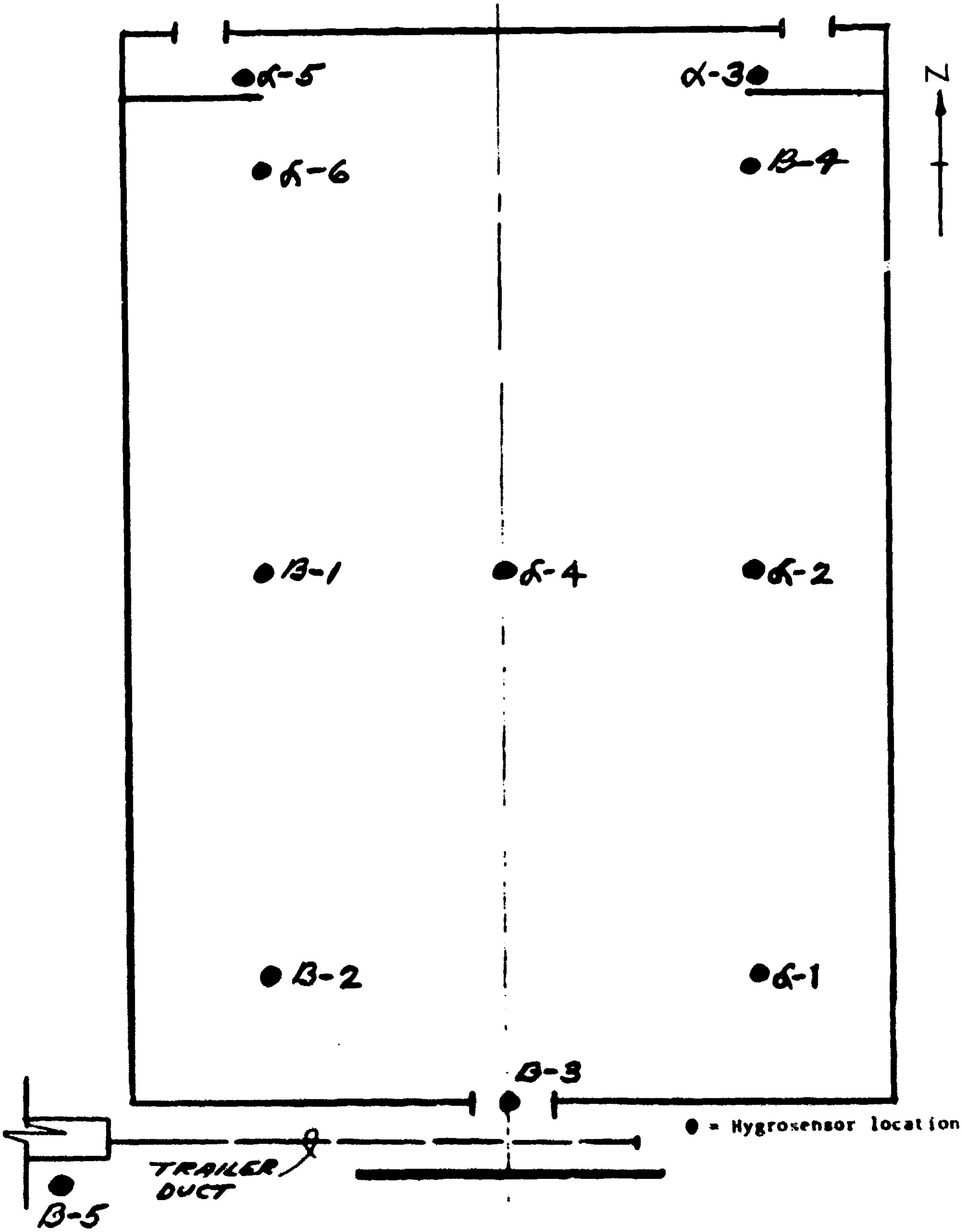


Figure C.4 Plan of hygrosensor locations.

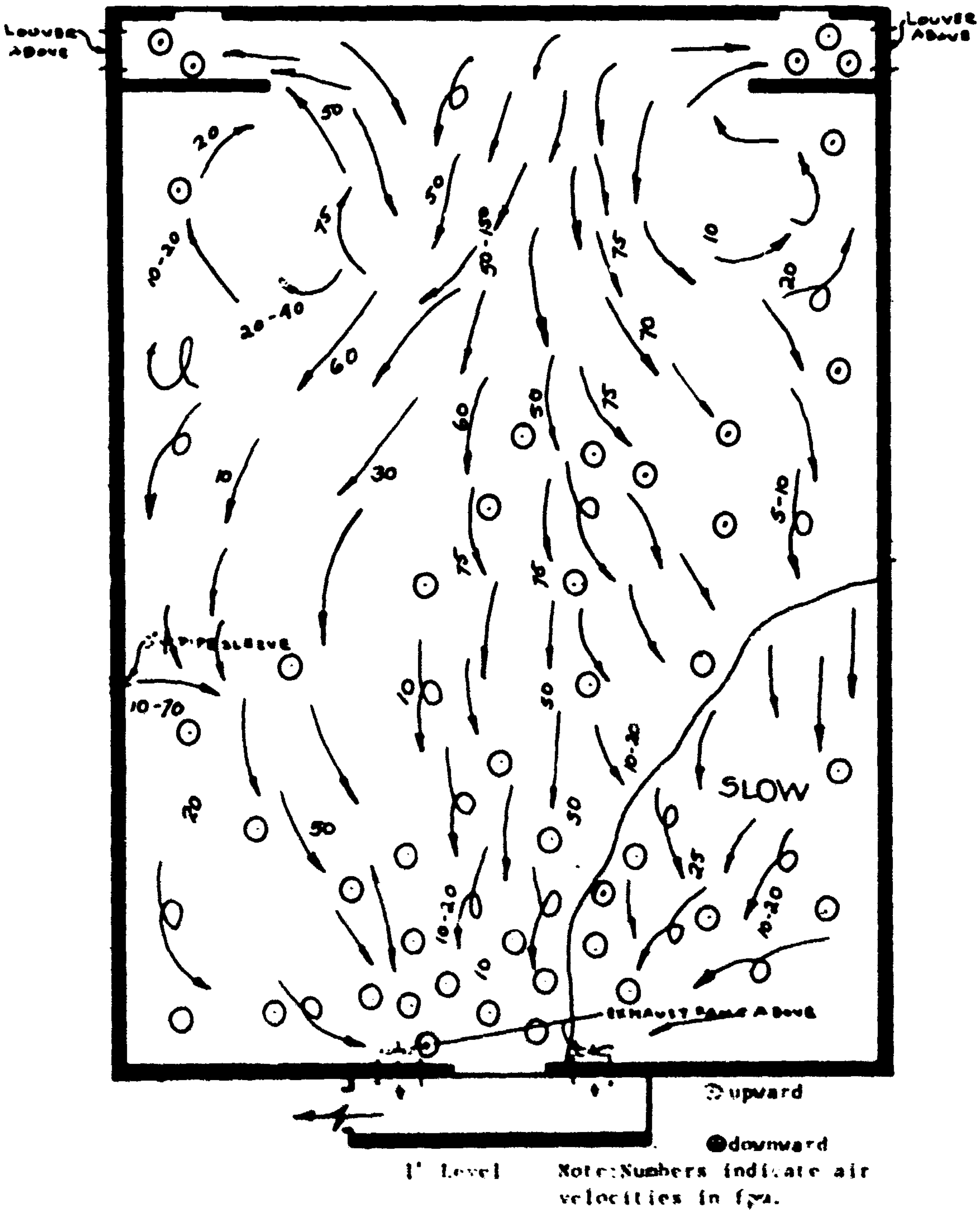
APPENDIX D

Velocity Traverse

Date - Time 6 Sept 66 - 1645 Air Flow 7200 CFM

Test No. 7 Phase III Condition

Remarks: Ventilation provided by shelter exhaust fans only.



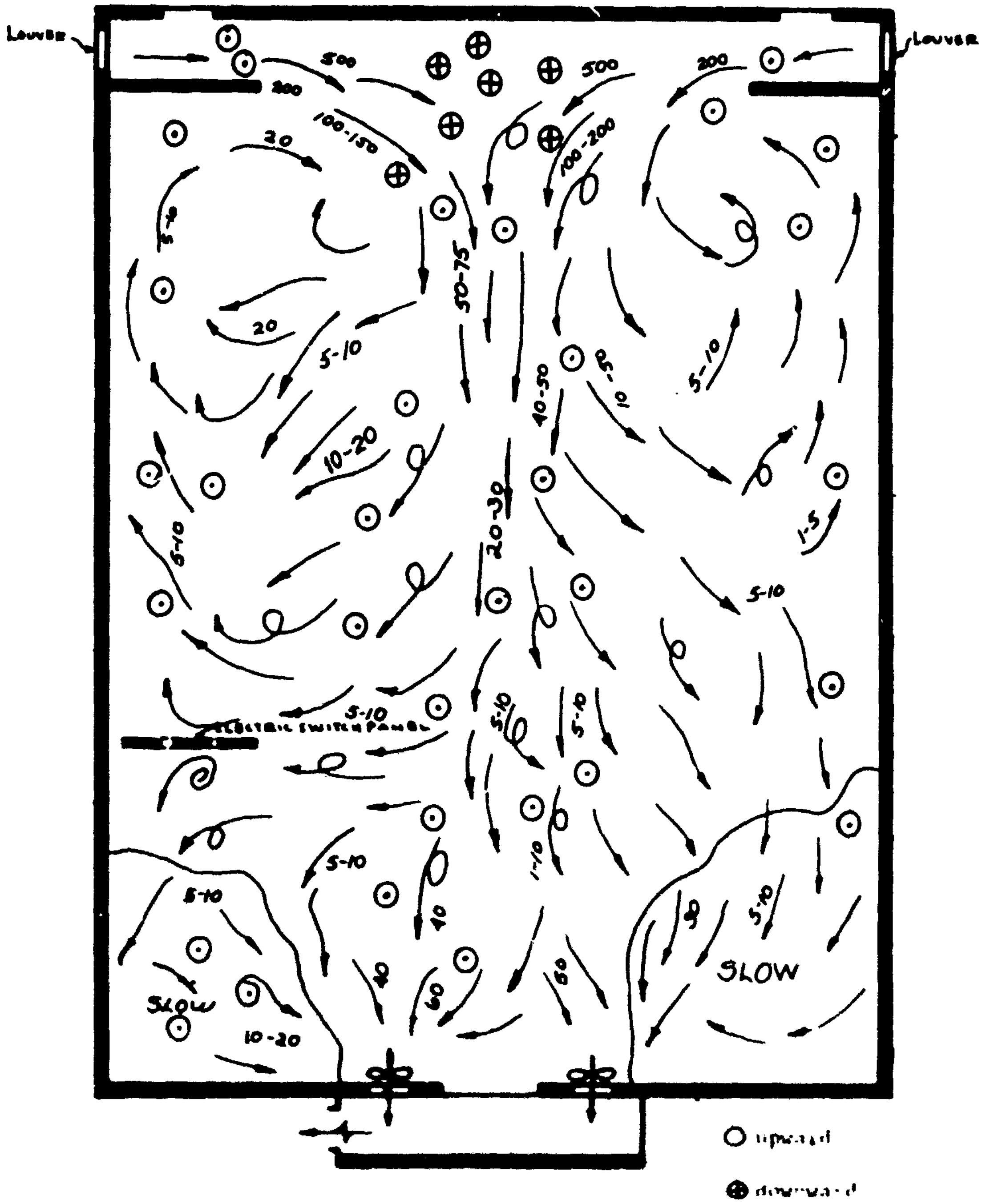
APPENDIX D

Velocity Traverse

Date - Time 6 Sept 1130 Air Flow 7200 CFM

Test No. 7 Phase III Condition

Remarks: Ventilation provided by shelter exhaust fans only.



5' Level Note: numbers indicate air velocities in fpm.

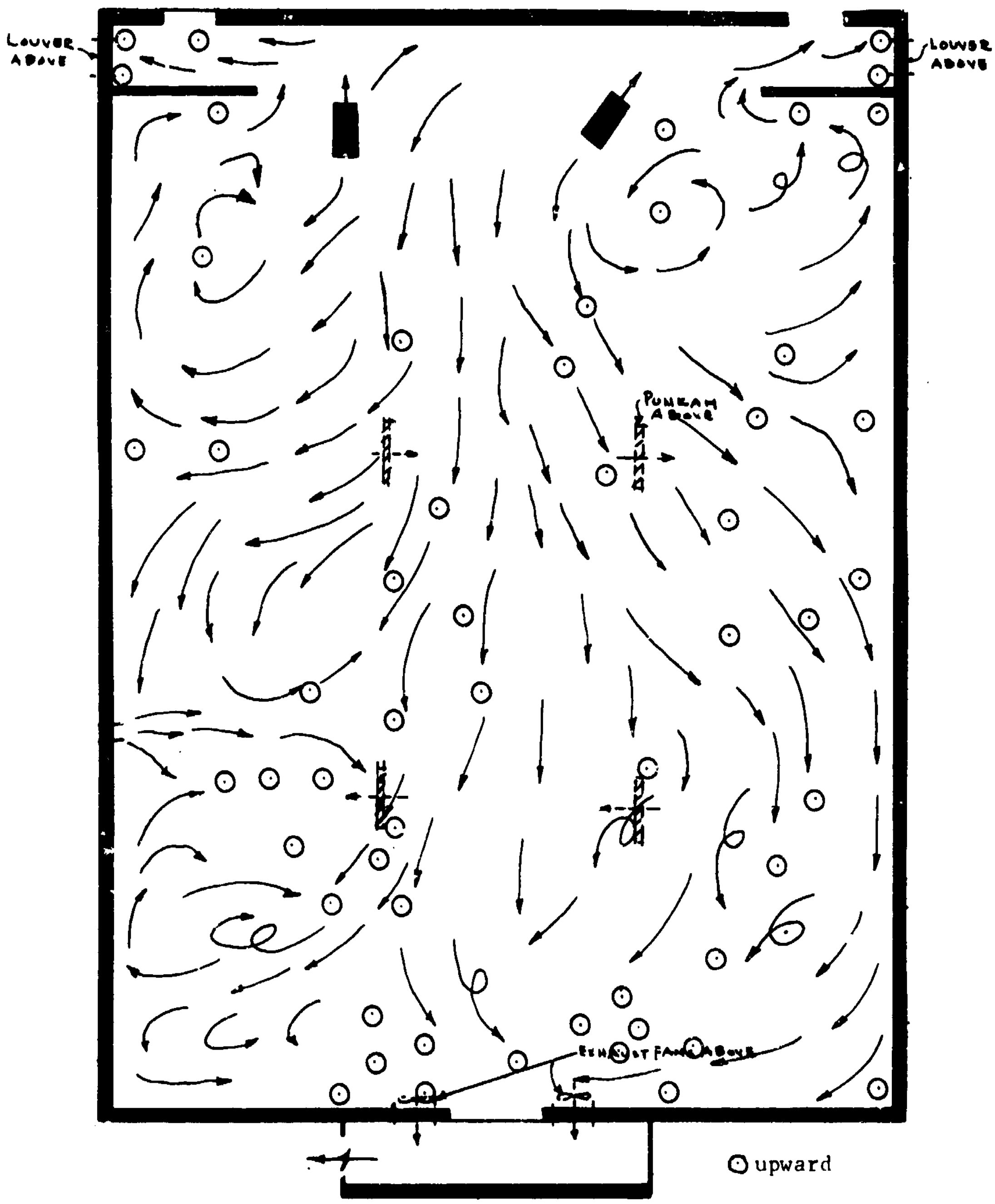
APPENDIX D

Velocity Traverse

Date - Time 6 Sept. 1445 Air Flow 7200 CFM

Test No. 7 Phase III Condition ______

Remarks: Ventilation by shelter exhaust fans and punkahs.



⊙ upward

⊕ downward

1' Level Note: Numbers indicate air velocities in fpm.

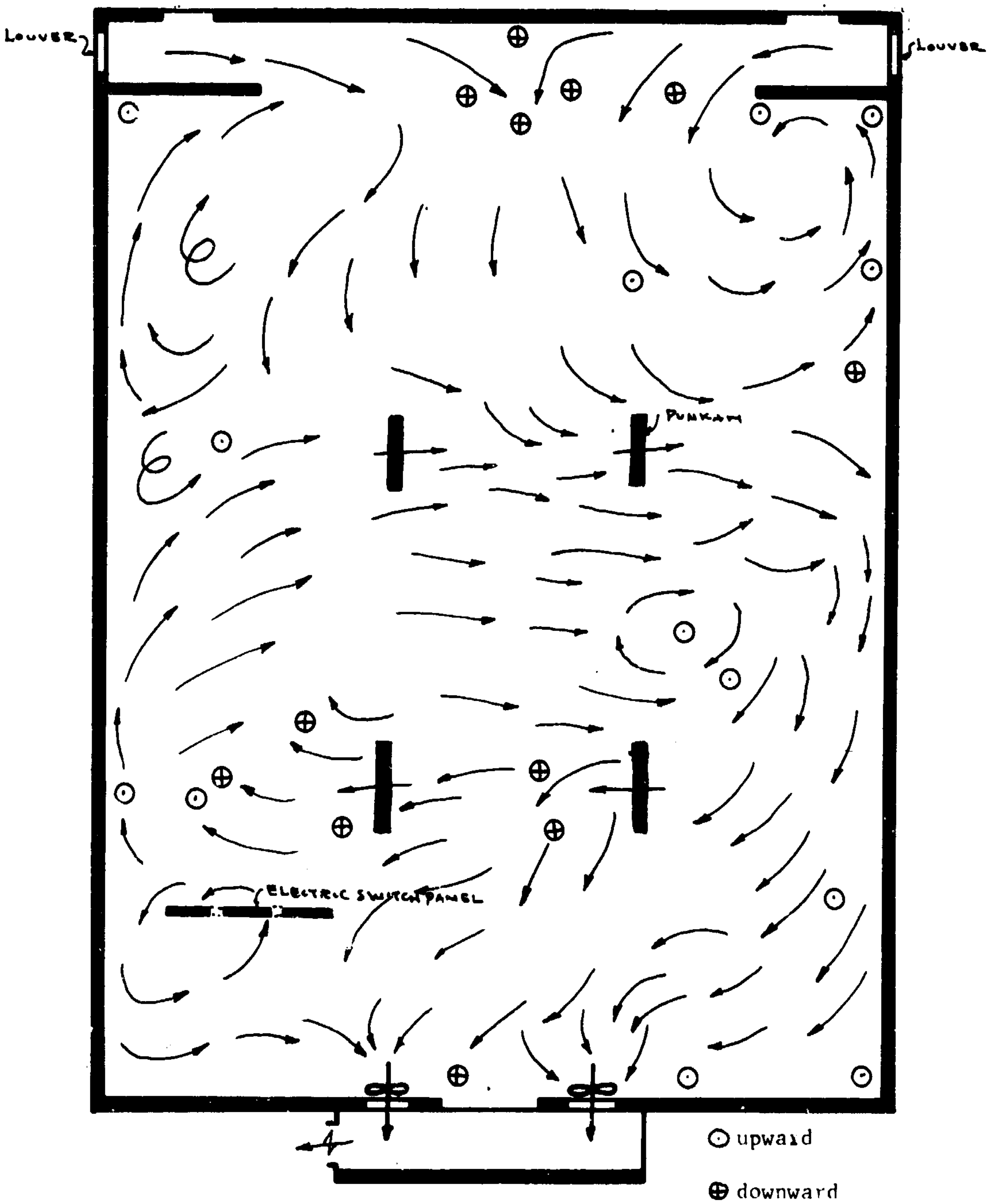
APPENDIX D

Velocity Traverse

Date - Time 6 Sept. 1445 Air Flow 7200 CFM

Test No. 7 PhaseIII Condition

Remarks: Ventilation by shelter exhaust fans and punkahs.



5' Level Note: Numbers indicate air velocities in fpm.

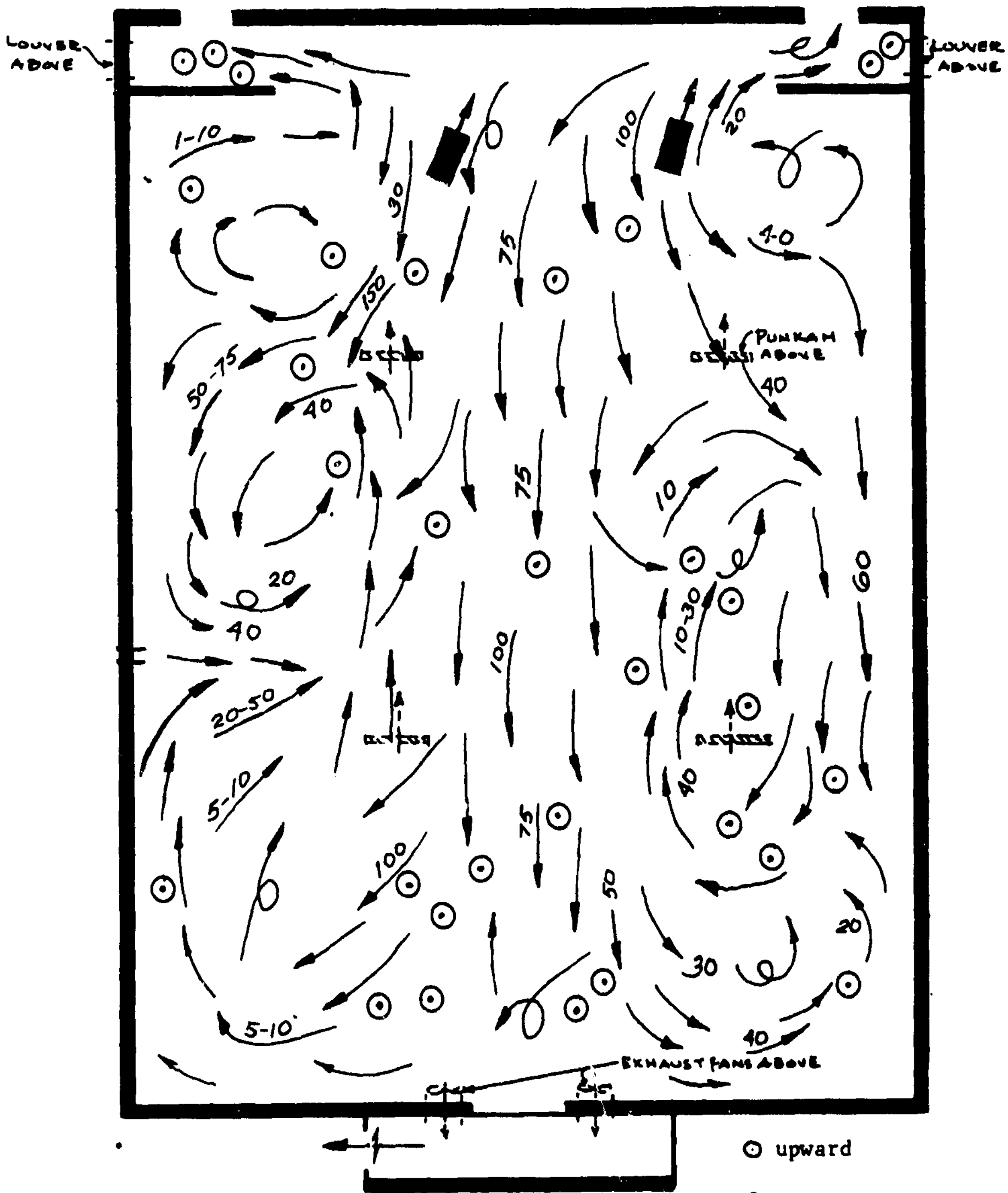
APPENDIX D

Velocity Traverse

Date - Time 7 Sept 1330 Air Flow 7200 CFM

Test No. 7 Phase III Condition ______

Remarks: Ventilation by shelter exhaust fans and punkahs.



⊙ upward

⊕ downward

1' Level

Note: Numbers indicate air velocities in fpm.

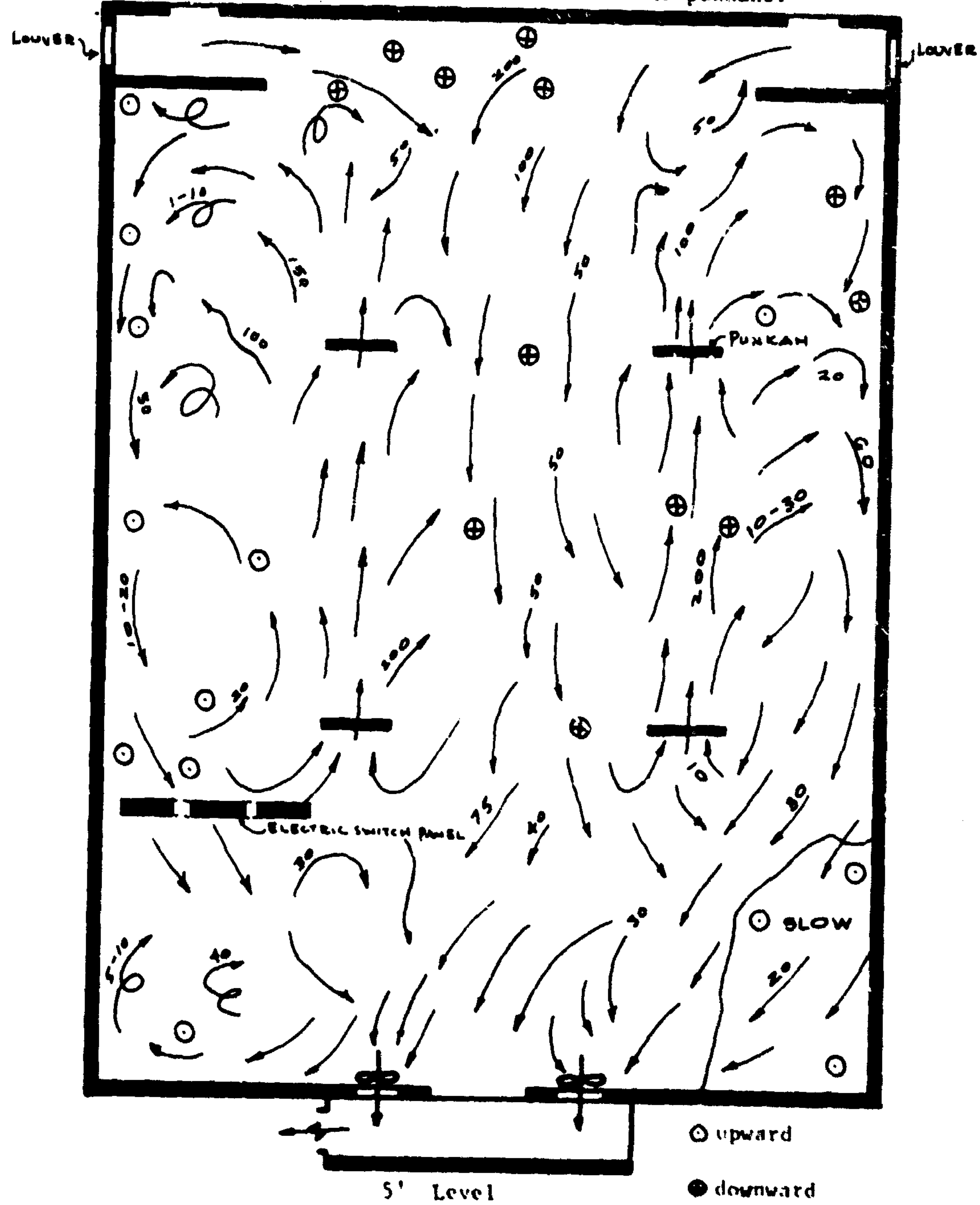
APPENDIX D

Velocity Traverse

Date - Time 7 Sept 1330 Air Flow 7200 CFM

Test No. 7 Phase III Condition ____________

Remarks: Ventilation by shelter exhaust fans and punkahs.



⊙ upward

⊕ downward

Note: Numbers indicate air velocities in fpm.

APPENDIX D

Velocity Traverse

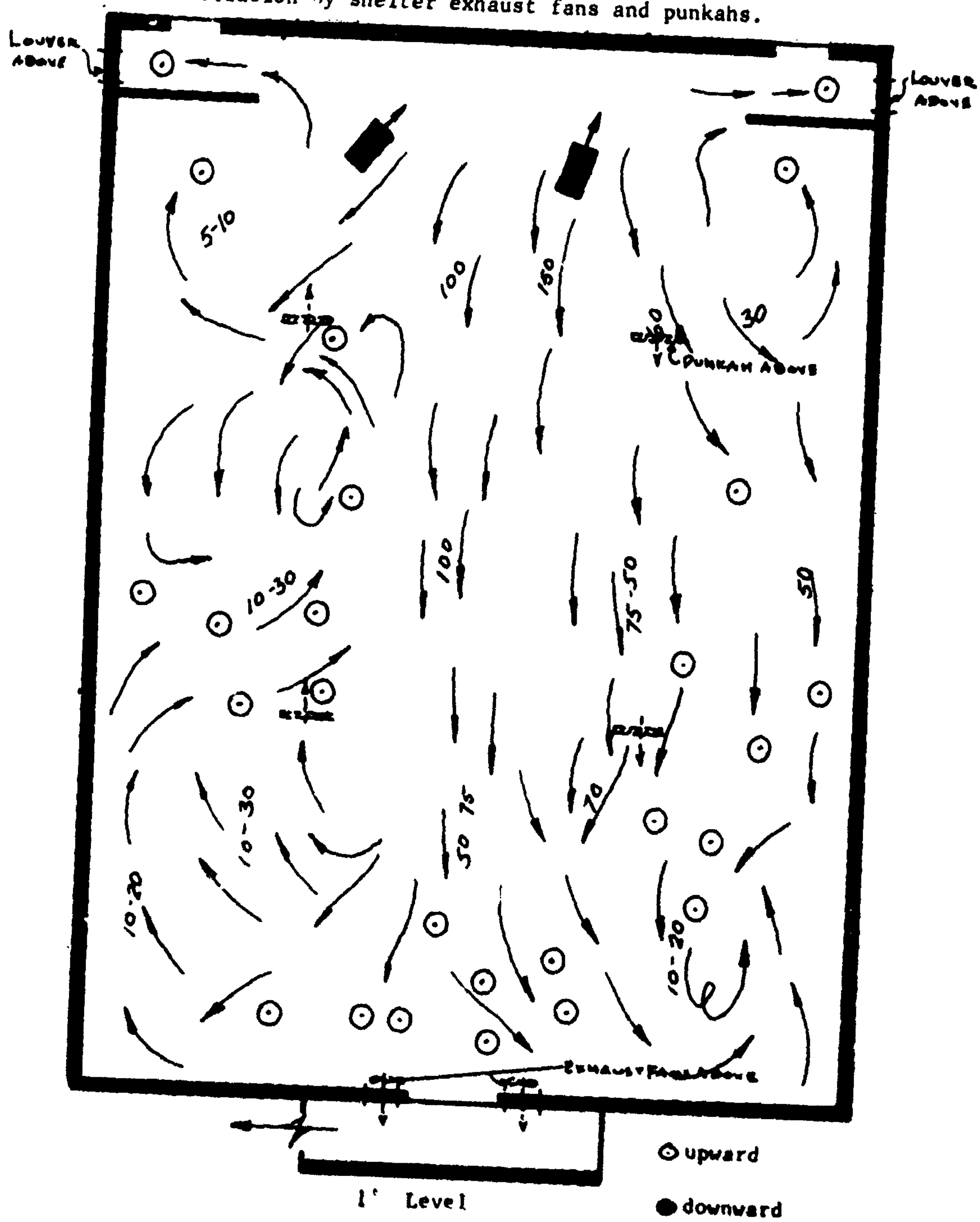
Date - Time 8 Sept 0900

Air Flow 7200 CFM

Test No. 7 Phase III

Condition

Remarks: Ventilation by shelter exhaust fans and punkahs.



Note: Numbers indicate air velocities in fpm.

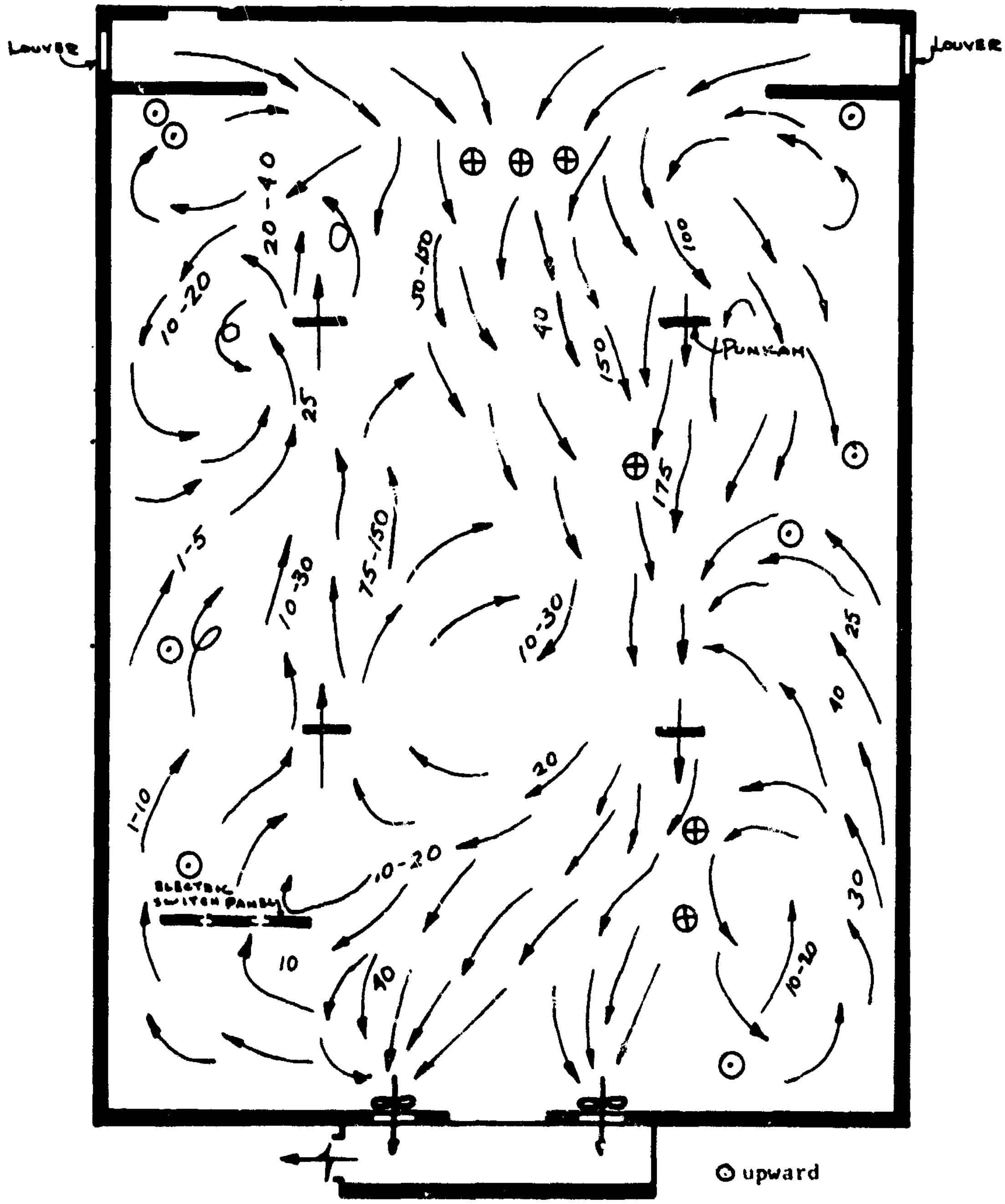
APPENDIX D

Velocity Traverse

Date -Time 8 Sept 0900 Air Flow 7200 CFM

Test No. 7 Phase III Condition ____________

Remarks: Ventilation by shelter exhaust fans and punkahs.



5' Level

Note: Numbers indicate air velocities im fpm.

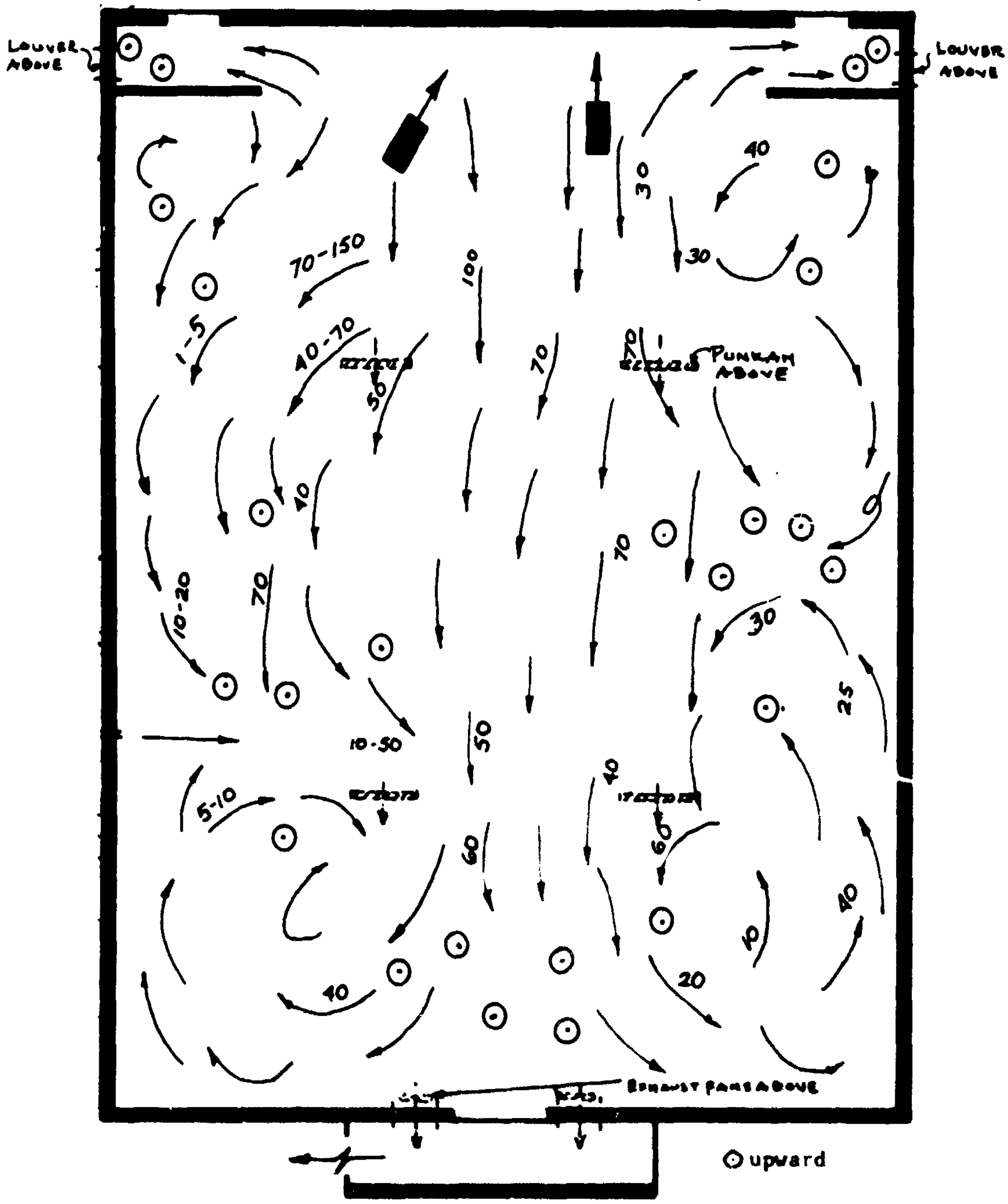
APPENDIX D

Velocity Traverse

Date - Time 8 Sept 1100 Air Flow 7200 CFM

Test No. 7 Phase III Condition

Remarks: Ventilation by shelter exhaust fans and punkahs.



○ upward

● downward

Note: Numbers indicate air velocities in fpm.

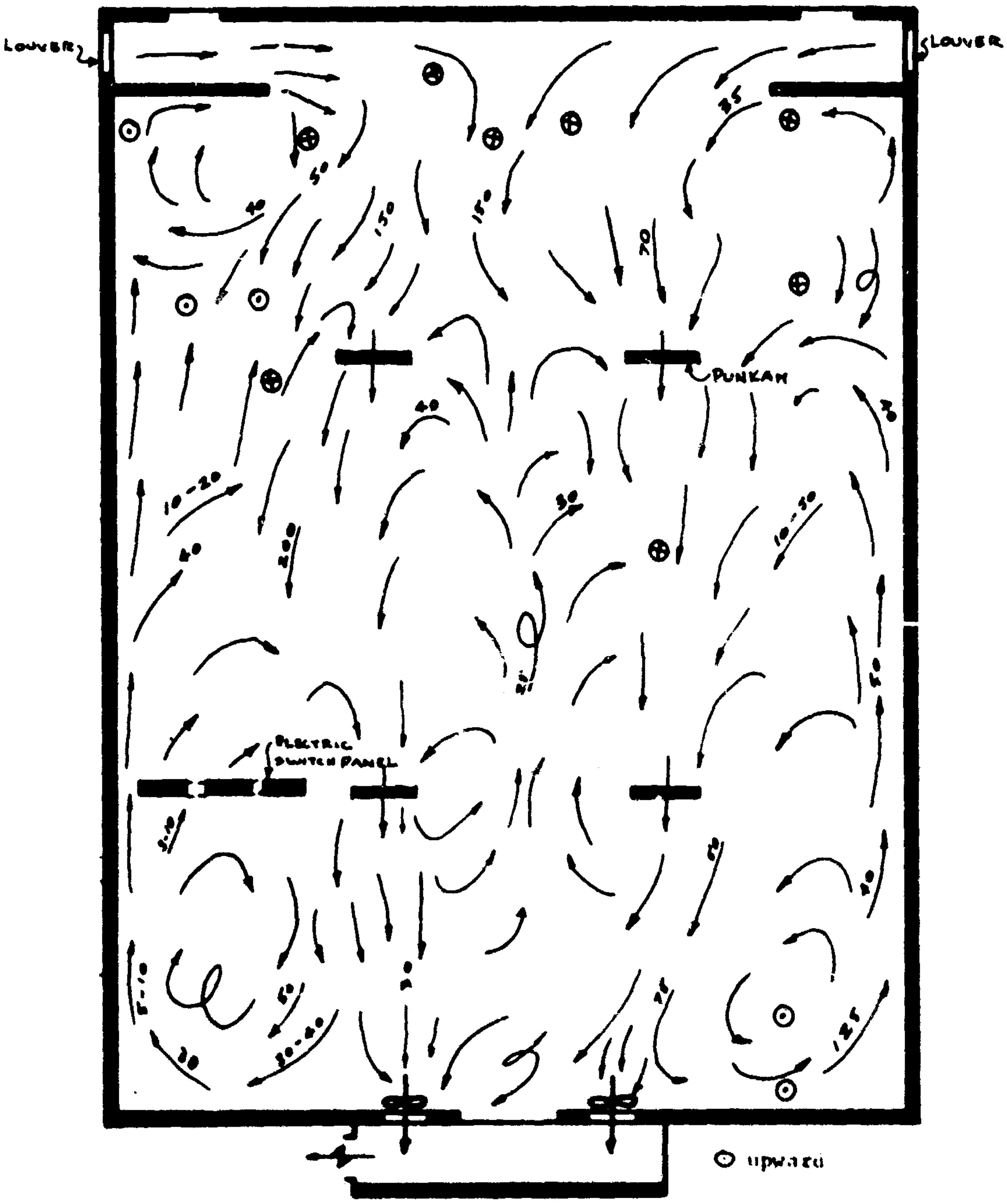
APPENDIX D

Velocity Traverse

Date - Time 8 Sept 1100 | Air Flow 7200 CFM

Test No. 7 Phase III | Condition

Remarks: Ventilation by shelter exhaust fans and punkahs.



5' Level

⊙ upward

⊕ downward

Note: Numbers indicate air velocities in fpm.

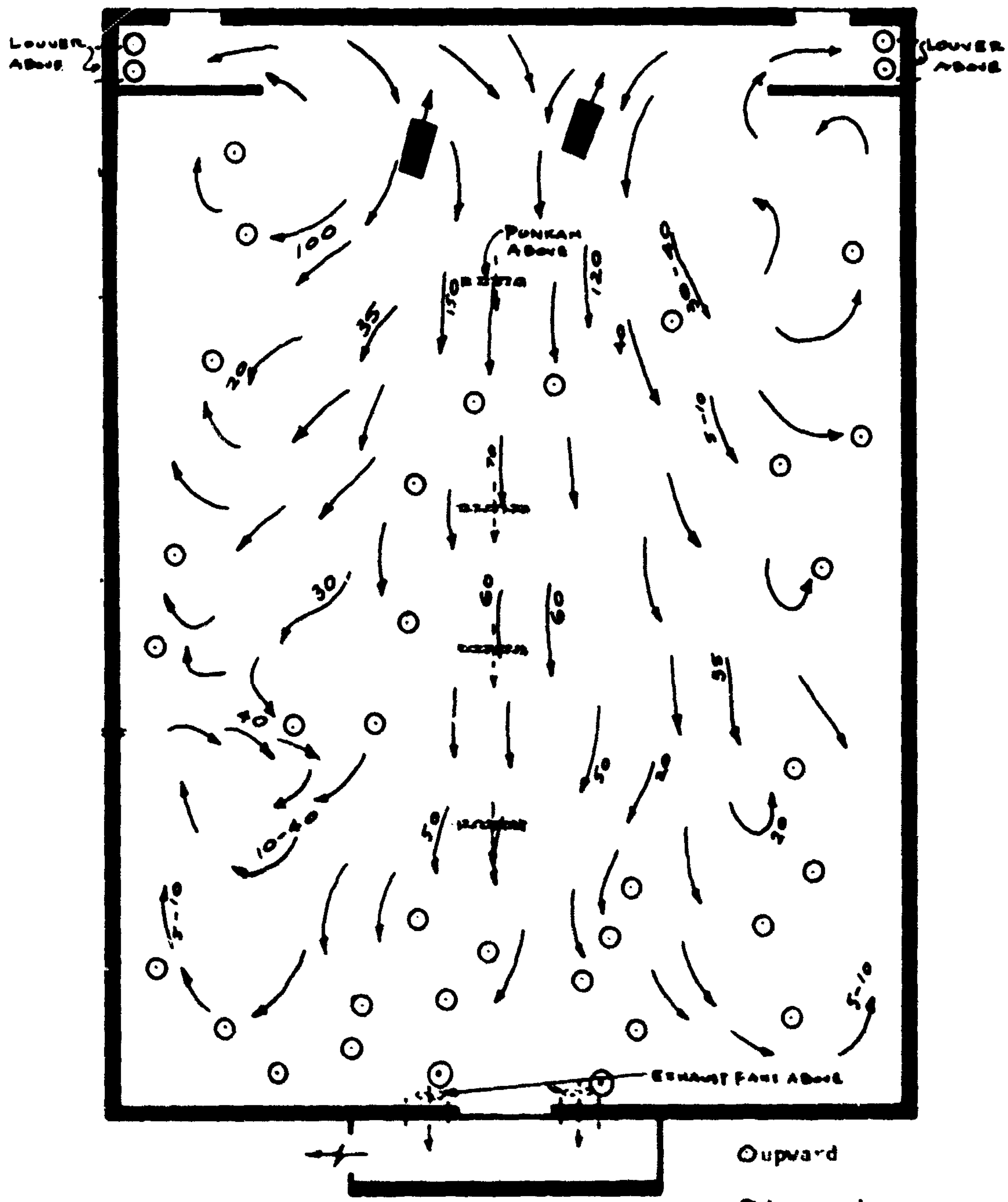
APPENDIX D

Velocity Traverse

Date - Time 9 Sept 0815 Air Flow 7200 CFM

Test No. 7 Phase III Condition

Remarks: Ventilation by shelter exhaust fans and punkahs.



1' Level

Note: Numbers indicate air velocities in fpm.

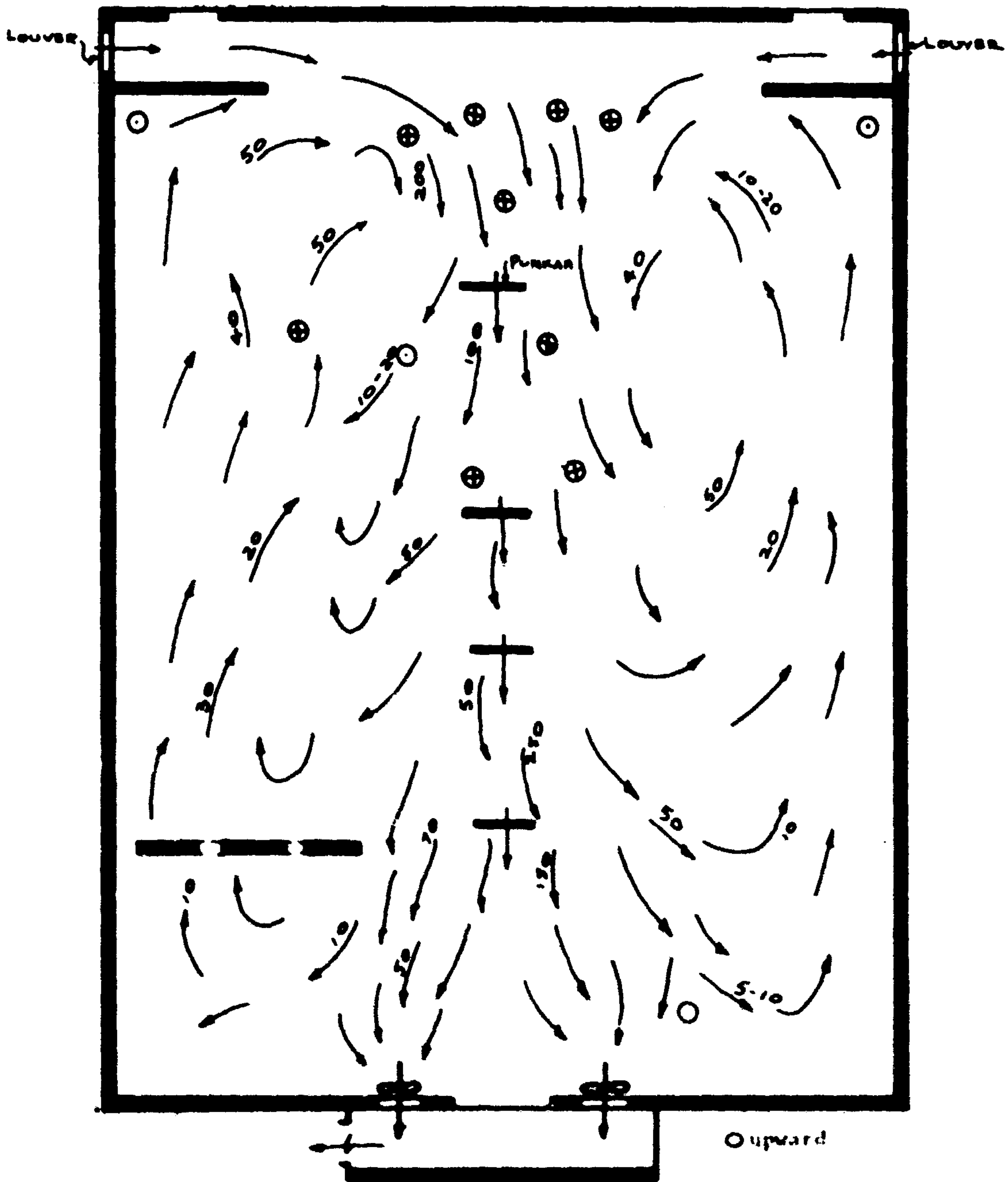
APPENDIX D

Velocity Traverse

Date - Time 9 Sept 0815 Air Flow 7200 CFM

Test No. 7 Phase III Condition ____________

Remarks: Ventilaton by shelter exhaust fans and punkahs.



○ upward

● downward

3' Level

Note: Numbers indicate air velocities velocities in fpm.

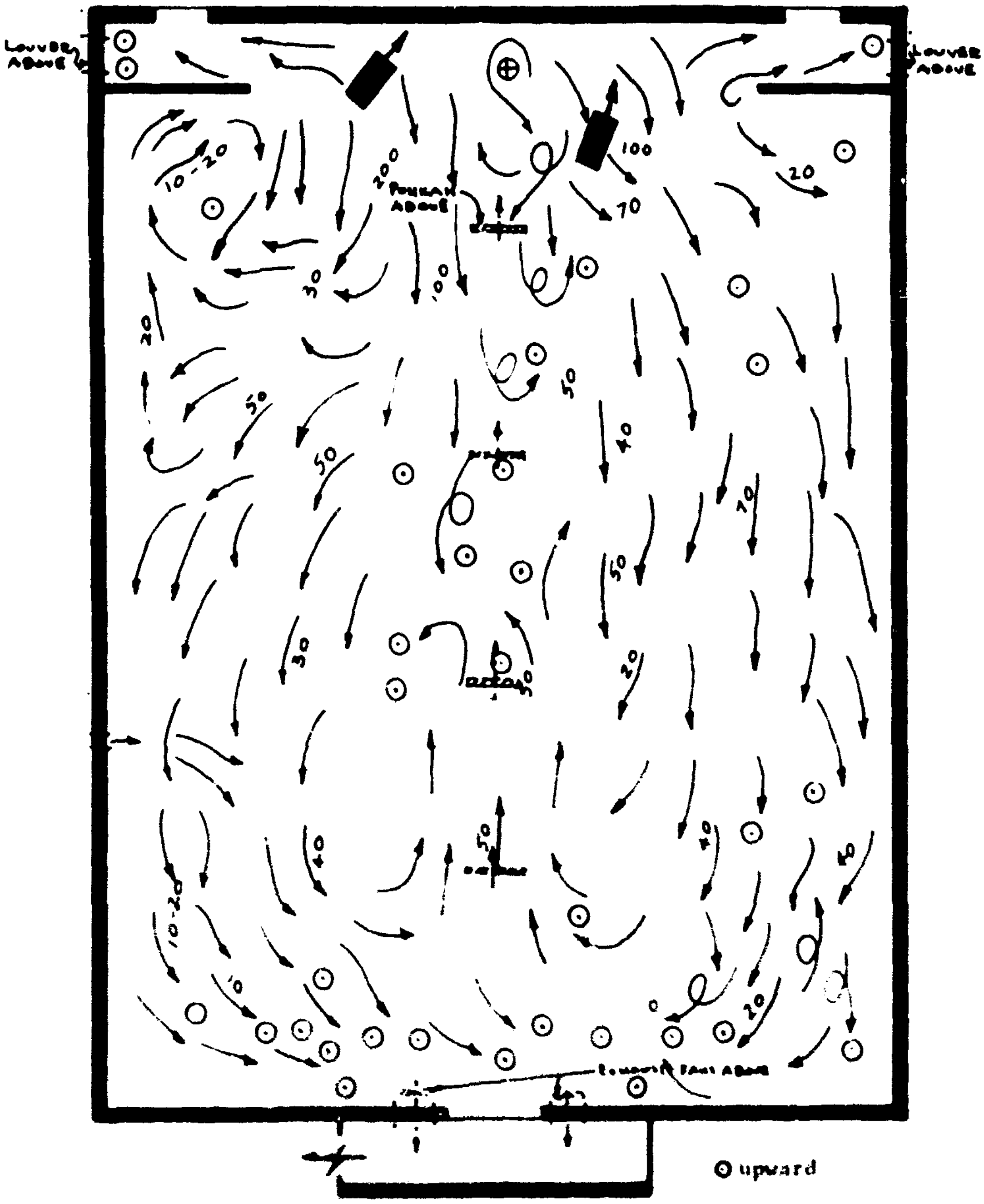
APPENDIX D

Velocity Traverse

Date - Time 9 Sept 1100 Air Flow 7200 CFM

Test No. 7 Phase III Condition

Remarks: Ventilation by shelter exhaust fans and punkahs.



O upward

● downward

1' Level

Note: Numbers indicate air velocities in fpm.

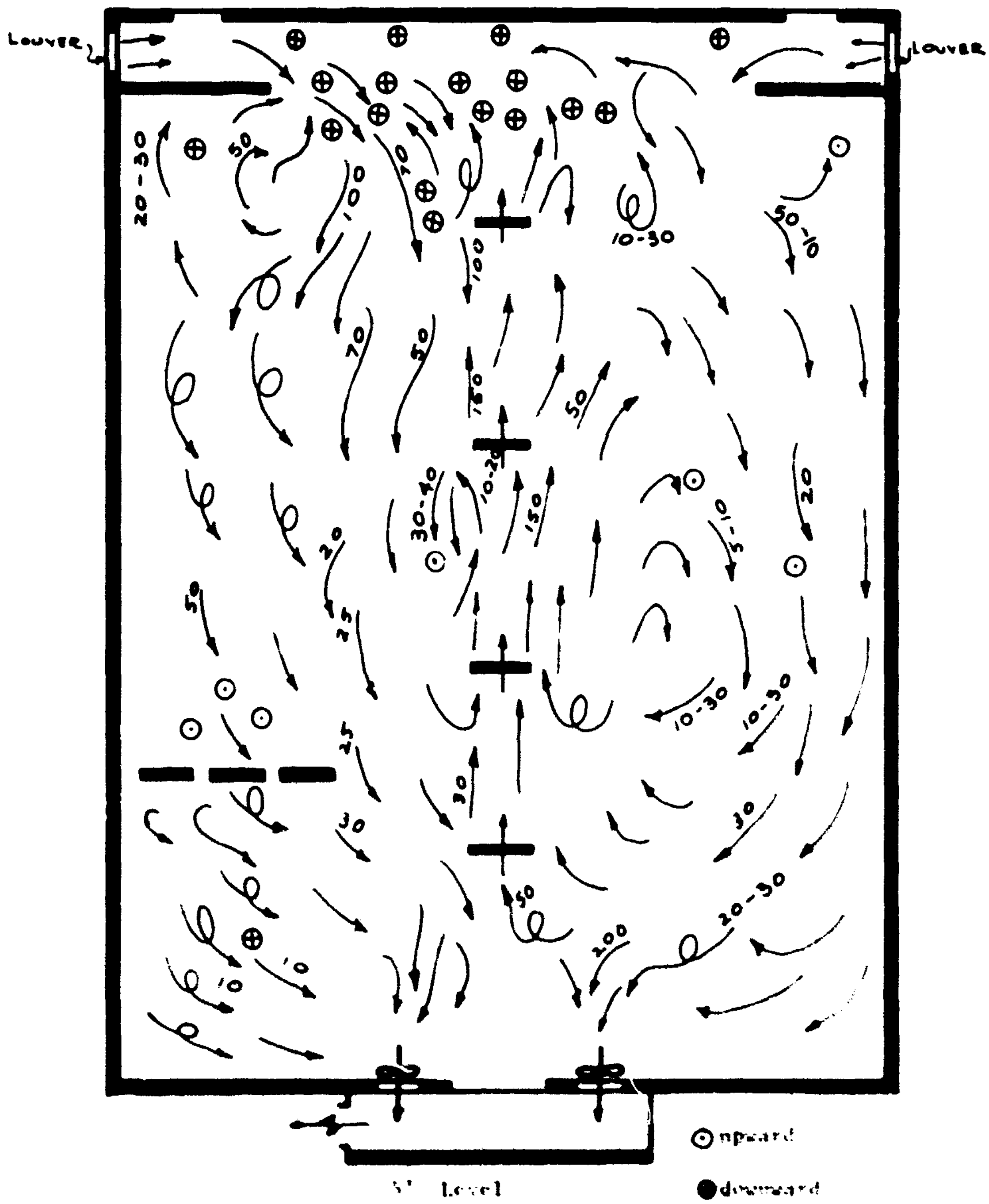
APPENDIX D

Velocity Traverse

Date - Time 9 Sept 1100 Air Flow 7200 CFM

Test No.7 Phase III Condition ____________

Remarks: Ventilation by shelter exhaust fans and punkahs.



Note: Numbers indicate air velocities in fpm.

APPENDIX E

Average Effective Temperature Over 24 Hour Period

DATE	TIME	ET	DATE	TIME	ET
10 AUG 1966	0700	78.7	11 AUG 1966	0700	81.7
	0800	79.8		0800	80.8
	0900	81.4		0900	80.0
	1000	81.0		1000	81.9
	1100	81.5		1100	82.3
	1200	82.3		1200	82.6
	1300	82.2		1300	83.5
	1400	82.7		1400	83.3
	1500	82.7		1500	82.9
	1600	82.9		1600	82.7
	1700	82.5		1700	82.2
	1800	82.1		1800	81.5
	1900	81.9		1900	81.7
	2000	81.8		2000	81.6
	2100	81.8		2100	80.1
	2200	81.0		2200	79.9
	2300	80.5		2300	79.2
	2400	80.3		2400	79.5
	0100	80.2		0100	79.0
	0200	80.3		0200	78.0
	0300	80.2		0300	78.0
	0400	80.2		0400	78.0
	0500	80.2		0500	77.4
	0600	79.8		0600	77.1
@15CFM/OCC. - 480 OCC. AVERAGE ET = 81.1			@15CFM/OCC. - 480 OCC. AVERAGE ET = 80.6		

APPENDIX E

Average Effective Temperature Over 24 Hour Period

DATE	TIME	ET	DATE	TIME	ET
13 AUG 1966	0700	79.2	14 AUG 1966	0700	81.0
	0800	80.7		0800	81.5
	0900	81.3		0900	[illegible]
	1000	81.8		1000	83.7
	1100	81.2		1100	83.9
	1200	[illegible]		1200	82.8
	1300	81.2		1300	83.1
	1400	[illegible]		1400	82.9
	1500	81.7		1500	83.4
	1600	82.3		1600	83.4
	1700	83.1		1700	[illegible]
	1800	82.5		1800	82.9
	1900	82.8		1900	[illegible]
	2000	82.3		2000	[illegible]
	2100	81.2		2100	82.1
	2200	81.9		2200	82.2
	2300	81.4		2300	81.3
	2400	81.3		2400	81.0
	0100	80.9		0100	81.0
	0200	81.1		0200	80.9
	0300	81.0		0300	[illegible]
	0400	81.0		0400	[illegible]
	0500	81.0		0500	[illegible]
	0600	80.9		0600	80.0
@12CFM/occ. —480 occ			@12CFM/occ. — 480 occ		
AVERAGE ET = 81.4			AVERAGE ET = 82.0		

APPENDIX E

Average Effective Temperature Over 24 Hour Period

DATE	TIME	ET	DATE	TIME	ET
15 AUG. 1966	0700	79.9	16 AUG. 1966	0700	81.1
	0800	81.0		0800	81.9
	0900	81.9		0900	82.6
	1000	82.5		1000	83.1
	1100	82.9		1100	83.5
	1200	83.2		1200	84.1
	1300	83.8		1300	83.9
	1400	84.4		1400	84.1
	1500	86.1		1500	84.1
	1600	83.5		1600	83.8
	1700	84.2		1700	84.0
	1800	83.0		1800	83.9
	1900	83.4		1900	83.9
	2000	83.0		2000	83.3
	2100	82.4		2100	83.2
	2200	82.2		2200	82.9
	2300	81.8		2300	82.3
	2400	82.1		2400	82.8
	0100	81.5		0100	82.2
	0200	81.4		0200	82.2
	0300	81.1		0300	82.1
	0400	80.9		0400	82.2
	0500	80.8		0500	82.1
	0600	81.0		0600	82.3
@12CFM/occ. – 480 occ			@12CFM/occ. – 480 occ.		
AVERAGE ET = 82.4			AVERAGE ET = 82.9		

APPENDIX E

Average Effective Temperature Over 24 Hour Period

DATE	TIME	ET	DATE	TIME	ET
18 AUG 1966	0700	80.2	21 AUG [illegible]	0700	81.4
	0800	81.5		0800	82.2
	0900	81.9		0900	82.8
	1000	82.1		1000	83.9
	1100	83.0		1100	83.8
	1200	83.2		1200	84.8
	1300	82.9		1300	84.5
	1400	83.5		1400	[illegible]
	1500	84.0		1500	85.2
	1600	83.5		1600	85.2
	1700	84.7		1700	[illegible]
	1800	83.3		1800	[illegible]
	1900	83.7		1900	84.7
	2000	83.2		2000	84.5
	2100	83.1		2100	[illegible]
	2200	82.8		2200	83.2
	2300	82.1		2300	82.9
	2400	82.0		2400	82.5
	0100	82.1		0100	[illegible]
	0200	82.0		0200	[illegible]
	0300	81.8		0300	81.9
	0400	81.5		0400	82
	0500	81.4		0500	81.5
	0600	81.8		0600	81.7
13.5 CFM/OCC – 480 OCC. AVERAGE ET = 82.6			14 CFM/[illegible] – 480 OCC. AVERAGE ET = 83.4		

APPENDIX E

Average Effective Temperature Over 24 Hour Period

DATE	TIME	ET	DATE	TIME	ET
22 AUG. 1966	0700	80.9	23 AUG. 1966	0700	80.9
	0800	[illegible]		0800	81.3
	0900	82.2		0900	82.2
	1000	82.7		1000	82.6
	1100	82.8		1100	82.8
	1200	[illegible]		1200	83.0
	1300	84.6		1300	82.3
	1400	83.2		1400	83.1
	1500	84.1		1500	82.8
	1600	[illegible]		1600	83.0
	1700	[illegible]		1700	82.2
	1800	83.1		1800	81.5
	1900	[illegible]		1900	81.2
	2000	82.8		2000	80.2
	2100	82.2		2100	80.7
	2200	[illegible]		2200	80.4
	2300	[illegible]		2300	79.9
	2400	82.5		2400	78.5
	0100	81.0		0100	79.1
AVG	0200	[illegible]		0200	78.5
	0300	[illegible]		0300	79.0
	0400	[illegible]		0400	78.4
	0500	[illegible]		0500	78.5
	0600	[illegible]		0600	77.0
@15CFM/[illegible] – 480 OCC. AVERAGE ET = 82.4			@15CFM/OCC. – 480 OCC AVERAGE ET = 80.8		

APPENDIX E

Average Effective Temperature Over 24 Hour Period

DATE	TIME	ET	DATE	TIME	ET
25 AUG. 1966	0700	79.5		0700	
	0800	80.8		0800	
	0900	80.9		0900	
	1000	81.5		1000	
	1100	82.4		1100	
	1200	82.3		1200	
	1300	81.9		1300	
	1400	82.7		1400	
	1500	82.7		1500	
	1600	82.4		1600	
	1700	82.8		1700	
	1800	82.3		1800	
	1900	83.9		1900	
	2000	82.4		2000	
	2100	82.3		2100	
	2200	82.4		2200	
	2300	80.9		2300	
	2400	80.9		2400	
	0100	81.1		0100	
	0200	81.1		0200	
	0300	80.2		0300	
	0400	80.2		0400	
	0500	80.0		0500	
	0600	80.0		0600	
7200 CEN TOTAL AVERAGE ET = 81.6 640 OCC.			AVERAGE ET =		

APPENDIX E

Average Effective Temperature Over 24 Hour Period

DATE	TIME	ET	DATE	TIME	ET
28 AUG. 1966	0700	80.4	29 AUG. 1966	0700	80.7
	0800	81.2		0800	80.6
	0900	81.8		0900	81.5
	1000	81.9		1000	81.5
	1100	82.1		1100	82.8
	1200	83.3		1200	83.5
	1300	85.1		1300	83.3
	1400	82.8		1400	83.4
	1500	83.1		1500	84.1
	1600	83.2		1600	83.8
	1700	83.8		1700	84.0
	1800	82.9		1800	83.8
	1900	82.7		1900	83.5
	2000	82.5		2000	83.0
	2100	82.5		2100	82.5
	2200	82.2		2200	82.3
	2300	81.6		2300	82.4
	2400	81.5		2400	82.0
	0100	81.7		0100	81.9
	0200	81.4		0200	81.9
	0300	81.3		0300	81.9
	0400	80.9		0400	82.0
	0500	80.5		0500	81.2
	0600	80.8		0600	81.0
640 OCC. - 7200CFM AVERAGE ET = 82.1			640 OCC. - 7200CFM AVERAGE ET = 82.4		

APPENDIX E

Average Effective Temperature Over 24 Hour Period

DATE	TIME	ET	DATE	TIME	ET
30 AUG 1966	0700	81.4	31 AUG 1966	0700	82.0
	0800	82.5		0800	82.1
	0900	83.2		0900	83.2
	1000	82.6		1000	83.0
	1100	83.1		1100	83.0
	1200	84.4		1200	83.2
	1300	84.6		1300	84.3
	1400	84.0		1400	83.8
	1500	84.5		1500	83.2
	1600	84.4		1600	84.5
	1700	83.7		1700	84.5
	1800	83.1		1800	84.8
	1900	83.6		1900	84.3
	2000	83.9		2000	83.9
	2100	84.4		2100	83.4
	2200	84.3		2200	83.2
	2300	83.9		2300	83.7
	2400	83.0		2400	83.0
	0100	83.1		0100	82.1
	0200	83.0		0200	81.9
	0300	82.1		0300	82.1
	0400	82.1		0400	81.8
	0500	82.0		0500	81.5
	0600	81.9		0600	81.[illegible]
640 OCC.-7200CFM			640 OCC- 7200CFM		
AVERAGE ET= 83.3			AVERAGE ET = 83.1		

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AD

Protective Structures Development Center, Fort Belvoir, Va.

PSDC-TR-23 1965

Simulated Occupancy Tests and Air Distribution in a 480-Person Community Shelter.

Results of simulated occupancy tests, determining the ventilation rate to maintain a habitable thermal environment in a 480-person shelter, and effects of manual auxiliary air moving devices on the air distribution patterns in the shelter, are furnished. Sand filling was used in the cavity and for the exterior hollow concrete masonry unit bearing walls and the roof. Two dual-unit exhaust fans provided 7200 cfm (total capacity) of ventilation. 15 cfm per occupant was required when ventilation air was conditioned to the Washington, DC, area at 90% reliability and 10 sq ft per person. Results agree with thermal analysis of the shelter. When overcrowded to 640 persons (7.5 sq ft/person) and ventilated at 15 cfm, at the same ambients, the average ET approached 85°. Plots of air velocity patterns were made for the ventilation conditions. Punkahs aid in distribution of the ventilation air.

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1. Ventilation
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3. Overcrowding
4. Air Distribution Patterns
5. Prototype Fallout Shelter
6. Effective Temperature
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13. ABSTRACT

Results of simulated occupancy tests determining the ventilation rate to maintain a habitable thermal environment in a 480-person community shelter are furnished. Effects of manual auxiliary air moving devices on the air distribution patterns in the shelter were observed. The shelter was an above ground, one-story structure. Sand filling was used for the exterior hollow concrete masonry unit bearing walls and the roof. The ventilation system consisted of two dual-unit exhaust fans, 7200 cfm total capacity, 15 cfm per occupant was required to maintain an average effective temperature (ET) in the shelter with ventilation conditioned to the Washington, DC, area at 90% reliability and 10 sq ft per person. Results obtained agree with thermal analysis of the shelter. When the shelter was overcrowded to 640 persons at 7-5 sq ft/person and ventilation at 15 cfm at the same ambients, the average ET was over 82° and approached 85° maximum. Plots of air velocity patterns were made using the installed ventilation system by itself and combined with punkahs. Punkahs were found to provide a more equitable distribution of the available ventilation.

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